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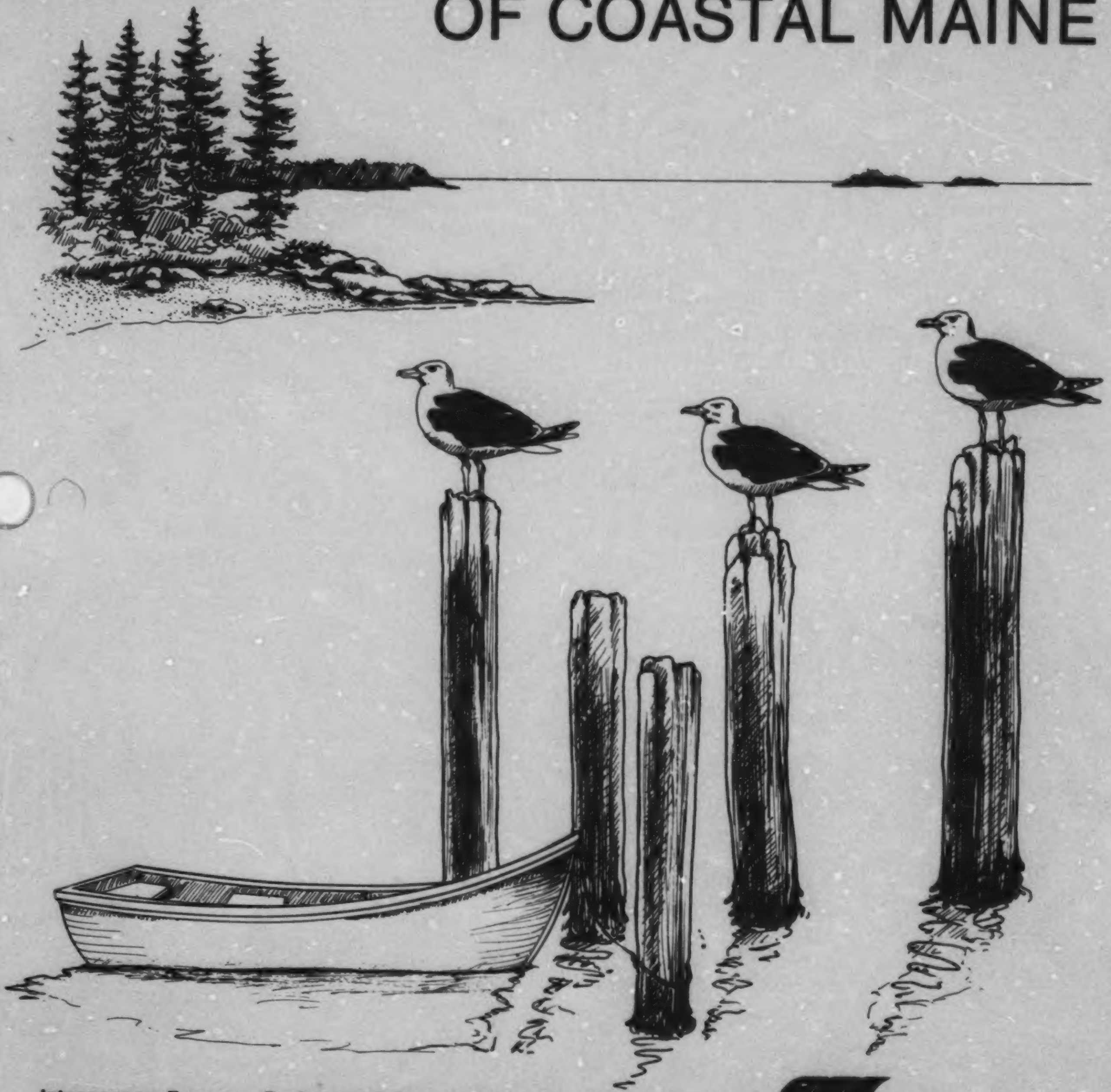

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The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems. The mission of the program is as follows:

- To strengthen the Fish and Wildlife Service in its role as a primary source of information on national fish and wildlife resources, particularly in respect to environmental impact assessment.

- To gather, analyze, and present information that will aid decisionmakers in the identification and resolution of problems associated with major changes in land and water use.

- To provide better ecological information and evaluation for Department of the Interior development programs, such as those relating to energy development.

Information developed by the Biological Services Program is intended for use in the planning and decisionmaking process to prevent or minimize the impact of development on fish and wildlife. Research activities and technical assistance services are based on an analysis of the issues, a determination of the decisionmakers involved and their information needs, and an evaluation of the state of the art to identify information gaps and to determine priorities. This is a strategy that will ensure that the products produced and disseminated are timely and useful.

Projects have been initiated in the following areas: coal extraction and conversion; power plants; geothermal, mineral, and oil shale development; water resource analysis, including stream alterations and western water allocation; coastal ecosystems and Outer Continental Shelf development; and systems and inventory, including National Wetland Inventory, habitat classification and analysis, and information transfer.

The Biological Services Program consists of the Office of Biological Services in Washington, D.C., which is responsible for overall planning and management; National Teams, which provide the Program's central scientific and technical expertise and arrange for contracting biological services studies with states, universities, consulting firms, and others; Regional Staff, who provide a link to problems at the operating level; and staff at certain Fish and Wildlife Service research facilities, who conduct inhouse research studies.

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(North and East of Cape Elizabeth)

Stewart I. Fefer and Patricia A. Schettig
Principal Investigators

Volume 1

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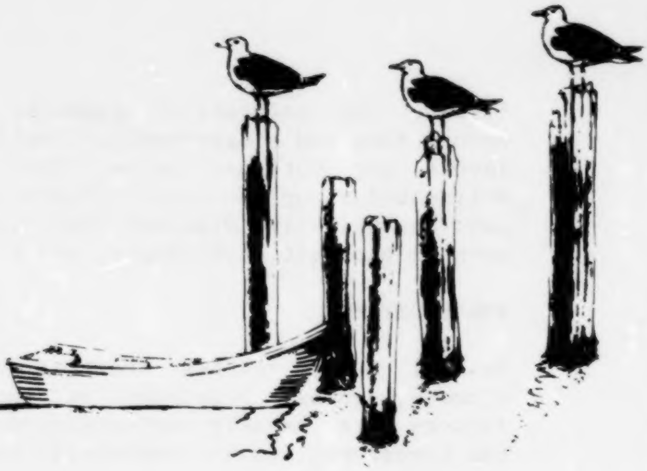
Chapter 1
Organization of the Characterization



Authors: Stewart Fefer, Patricia Shettig

The purpose of an ecological characterization is to outline and describe the major ecological elements and processes in a specific area. This characterization describes the approximately 4000-mile area of the Maine coast north and east of Cape Elizabeth (figure 1-1). It attempts to clarify the current state of knowledge of this ecosystem by synthesizing and integrating existing biological, physical, and socioeconomic information. It provides information on the natural resources of coastal Maine in an ecological framework designed to guide resource management and coastal planning and to aid in the evaluation of human impacts on the ecosystem.

An ecosystem is the sum of interactions between living organisms and their environment. Organisms are influenced by each other as well as by the physical elements and processes surrounding them. People are an important part of any ecosystem. We influence and are influenced by other elements and processes in our environment. In order to manage and maintain natural resources effectively, and to guide development generated by social and economic demands, we must better understand how ecosystems function.

The Maine coast is a mosaic of solid bedrock and unconsolidated glacial deposits overlain with recent sedimentary deposits and soil. It exhibits a large variety of habitats, including intertidal flats, rocky shores, estuaries, islands, rivers, streams, lakes, marshes, bogs, forests, and agricultural and developed lands. These habitats support diverse communities of fish, wildlife and plants. This ecosystem was selected for study because of its biological diversity and its proximity to proposed energy development activities (oil and gas production and refining and tidal power, hydropower, coal-fired power, and nuclear power generation) that may affect its ecology.

The coast of Maine is described here from three perspectives: (1) the ecosystem, the Maine coast as a whole; (2) the systems (marine, estuarine, riverine, lacustrine, palustrine, forest, and agricultural and developed land); and (3) the species that inhabit these systems (e.g., waterfowl, fishes, and terrestrial mammals; figure 1-2). The major processes (e.g., energy flow and biogeochemical cycling) are discussed at each level: the four levels are outlined below. For organizational purposes six regions were delineated along the coast (figure 1-1). These regions are not necessarily physiographically distinct but are subject to similar environmental forces, such as geologic, hydrologic, and climatic.

THE ECOSYSTEM

Several major forcing functions operate throughout the ecosystem, including climate, geology, hydrology, and the socioeconomy. The influences of these factors are greatly interrelated. Climatic and geological events influence the topography, soils, sediments, and hydrology of the entire coast. Changes in substrata and hydrology affect vegetation, which in turn affects the fauna. Socioeconomic activities both influence and are influenced by the physiography of the ecosystem. Human activities can change in a short time what natural processes have created over centuries. Chapter 2 describes the geography of the Maine coast and examines the influences of these forcing functions on the ecosystem. Chapter 3 discusses human impacts on the ecosystem.

THE SYSTEM

A system is a particular type of habitat that is influenced by a unique set of hydrological, geomorphological, chemical, and biological factors. The classification of the Maine coast by system, subsystem, and class is based on the U.S. Fish and Wildlife Service's (FWS) Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et al. 1979) and Maine State Planning Office's Classification System For Land Cover in Maine (figure 1-3).

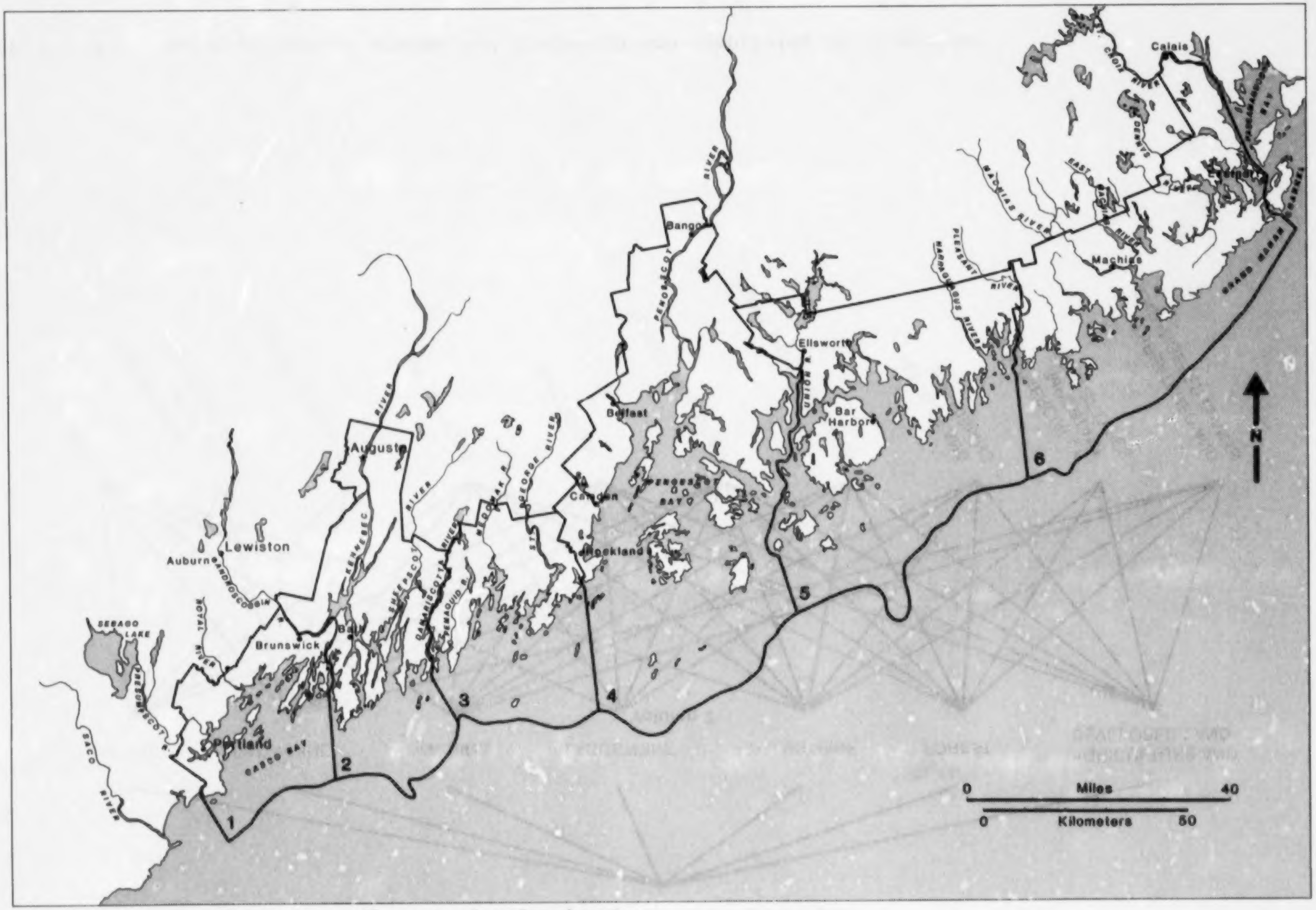
The systems are reviewed individually in chapters 4 through 10 and each is described in terms of characteristic components, functions, and interactions. To illustrate the functions of and interactions between systems, four major aspects of the ecosystem will be examined:

1. energy flow
2. biogeochemical cycles
3. biota
4. abiota

These do not function exclusively but overlap and complement each other. They are outlined briefly below and illustrated in figure 1-4.

Energy flow

Ecosystems require energy to support life, and the ultimate source of energy for all natural ecosystems is the sun. Through a process known as photosynthesis, green plants capture solar energy and use it to transform carbon dioxide and nutrients into utilizable forms (carbohydrates). External forces affecting this transfer of solar energy include hydrological factors (currents, tides, and freshwater flows), climatic factors (wind, insolation, and ice formation), geological factors (soil type and composition), and chemical factors (ionorganic and organic nutrients). Human activities (pollution, habitat modification, and natural resource utilization) also affect energy transfer.


Calais
ST. CROIX RIVER
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PASSAMAQUODDY BAY
Eastport
EAST MACHIAS RIVER
MACHIAS RIVER
Machias
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NARRAGUAGUS RIVER
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UNION R.
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ANDROSCOGGIN R.
ROYAL RIVER
Brunswick
Bath
SEBAGO LAKE
PRESUMPSCOT R.
Portland
CASCO BAY
SACO RIVER
1
2
3
4
5
6
N
0
Miles
40
0
Kilometers
50

Figure 1-1. The Maine Coast Characterization Area.

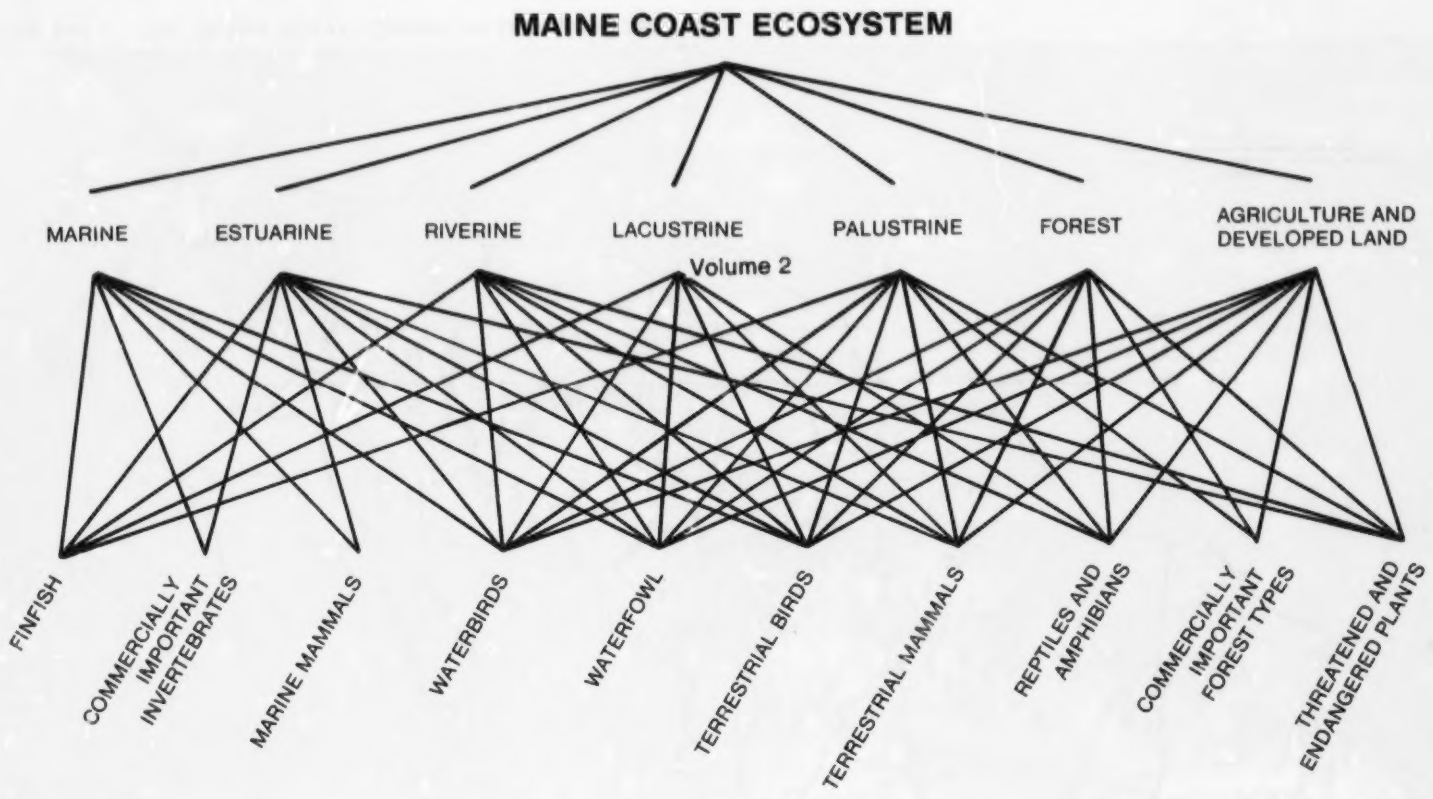
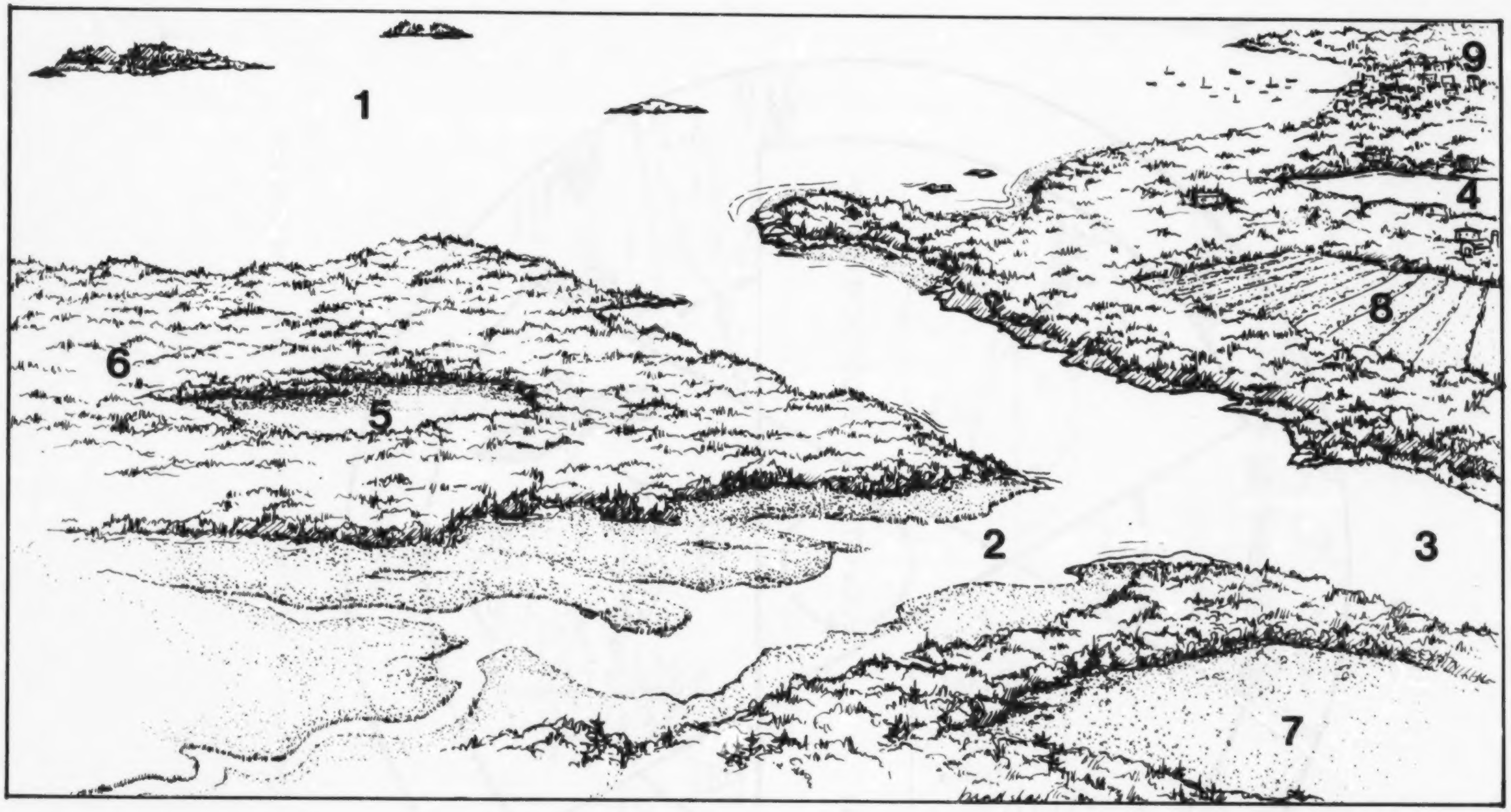

MAINE COAST ECOSYSTEM
MARINE
ESTUARINE
RIVERINE
LACUSTRINE
PALUSTRINE
FOREST
AGRICULTURE AND DEVELOPED LAND
Volume 2
FINFISH
COMMERCIALLY IMPORTANT INVERTEBRATES
MARINE MAMMALS
WATERBIRDS
WATERFOWL
TERRESTRIAL BIRDS
TERRESTRIAL MAMMALS
REPTILES AND AMPHIBIANS
COMMERCIALLY IMPORTANT FOREST TYPES
THREATENED AND ENDANGERED PLANTS

Figure 1-2. Major ecological systems and species groups comprising the ecosystems.



1	MARINE	6	FOREST
2	ESTUARINE	7	NONFOREST
3	RIVERINE	8	AGRICULTURE
4	LACUSTRINE	9	DEVELOPED LAND
5	PALUSTRINE		

Figure 1-3. Ecological systems of the Maine coast.

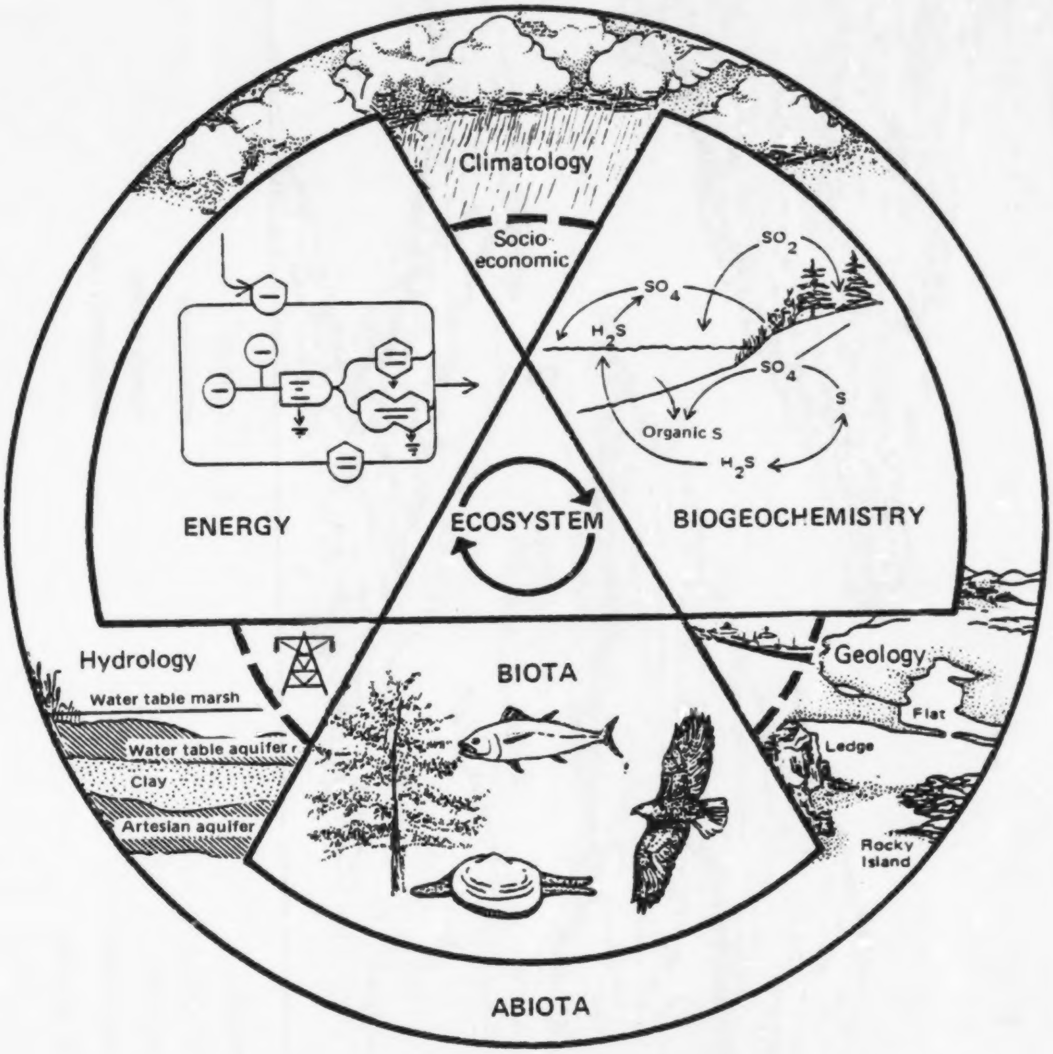

Climatology
Socio-economic
SO_2
SO_4
H_2S
SO_4
S
Organic S
H_2S
ENERGY
ECOSYSTEM
BIOGEOCHEMISTRY
Hydrology
Water table marsh
Water table aquifer
Clay
Artesian aquifer
BIOTA
Geology
Flat
Ledge
Rocky Island
ABIOTA

Figure 1-4. The conceptual framework of the characterization.

The process by which plants utilize and store solar energy in the form of organic substances is called "primary production." The rate at which primary production takes place is called "primary productivity" (Odum 1971). The total amount of organic matter created is called "gross primary production." Roughly 20% to 50% of the captured energy is lost in plant respiration, yielding a net primary production of roughly one-half the gross primary production. This net production results in the creation of plant materials that eventually may be consumed by animals (herbivores and detritivores).

Energy is passed from producers to consumer organisms of different trophic (feeding) levels through food webs. At the base of the food web are the primary producers: phytoplankton, benthic microalgae, and macrophytes (marsh grasses, terrestrial plants, and macroalgae).

Plant eaters, or herbivores, occupy the next position in the food web, the primary consumer level. Carnivores, which eat the herbivores, form the secondary consumer level; and other carnivores that feed on the secondary consumers occupy the tertiary consumer level. Additional levels of consumers may exist, as well as an intermediate level of omnivores that feed on more than one level of the food web.

The following rules apply to energy transfer between trophic levels:

1. Within each level in the trophic structure, energy is used for maintenance and growth. It is stored in the form of carbohydrates, fats, and proteins and eventually passes to the decomposers through excretion and death.

2. Between one trophic level and the next, considerable loss (roughly 90%) of energy takes place. It is lost through consumption by organisms in breathing, feeding, and reproducing, and in activities such as migration, defense, burrowing, nest building, and courtship.

Decomposers (bacteria, fungi, insects, and invertebrates) return inorganic substances to the pool of available nutrients by oxidizing dead organic matter. Waste products from the ecosystem (dead animals and plants, detritus, and feces) are colonized by a succession of decomposers. Decomposers break down organic material metabolically and return valuable materials to the soil or water column. Nutrients are then recycled by primary producers to form organic compounds via photosynthesis.

The flow of energy through the food web representive of a marine system in eastern coastal Maine is illustrated in figure 1-5. The solid lines show the direction in which energy flows. The sun (1), particularly during the summer months, provides energy for the blooming of the phytoplankton. Phytoplankton are the food of zooplankton (2), and both are the food of numerous species of intertidal (3) and subtidal (4) animals, krill (e.g., euphausiids, mysid shrimp; 5), and smaller fishes (6). Medium-sized fishes (7) feed on euphausiids, mysid shrimp and smaller fishes, and all of these are food for the larger species, such as tuna and shark (8), whales, porpoises, seals (9), people (10), and birds (11). When the larger animals die their bodies are absorbed rapidly into the system by scavenging starfish, urchins, sea fleas, herring gulls, and other creatures. During life, all of the animals return vital materials to the sea in feces. The nutrients (12) contained in feces are vital to the growth of phytoplankton, macroalgae, and emergent wetland plants, which are the basis of the food web of the coastal Maine ecosystem.

Energy flow through a system has been described by H. T. Odum (1966) using a circuit language (energese) that he developed. Energy flow modeling by circuit language clarifies relationships among the climatic, biological, hydrological, geological, and socioeconomical components of a system.

The flow of energy through a generalized ecological system is illustrated in figure 1-6. The symbols employed are explained in figure 1-7. Photosynthesis by producer organisms is controlled by certain forcing functions (e.g., sunlight) and the availability of stored compounds (i.e., nutrients). Producers provide energy to consumers either directly, through herbivory, or indirectly, through the feeding of some consumers on partially decomposed plant material (detritus). These consumers, in turn, are preyed upon by higher level consumers. Some energy is recovered through excretion and death. Energy is lost at each transfer to heat (respiration).

In order to compare the relationships in a generalized ecosystem to those in a natural community, the energy flow in an eelgrass community is examined briefly below. The forcing functions that drive photosynthesis in eelgrass beds are sunlight, currents, and salinity. Required nutrients are derived from the water column or sediments. The eelgrass is consumed directly by herbivores (e.g., snails and brant). Plant parts and dead eelgrass decompose through microbial action and are consumed by detritivores (e.g., clams). Secondary consumers, such as fish and black ducks, feed on those primary consumers. Nutrients are returned through excretion and death via the detrital-microbial complex. When a system is impacted by functional change or by the addition or elimination of a component, the effects on its energy flow are many and complex. In the estuarine system, for example, if the characteristics of the tides (height, frequency, and duration) are changed (tidal dams), then the habitats that require the previous tidal regime (e.g., salt marshes, mud flats, sand flats, eelgrass, and rocky shores) will change and the food webs associated with those habitats will change.

Biogeochemical Cycling

As energy flow represents the transfer of energy along food chains, biogeochemical cycles illustrate the mode and direction of the transfer of materials through systems. Biogeochemical cycles are closed and represent continuous movement of materials (e.g., carbon, oxygen, water, and nutrients) among the living and nonliving parts of the ecosystem. Many of these elements are essential to living processes and structures.

Meteorological, geological, biological, and oceanographical forces or vectors drive biogeochemical cycles. Wind, rain, snow, ice, fog, and gasses bearing dissolved and particulate matter are meteorological vectors. Gravity (e.g., streamflow) is a geological vector. Tides and currents and changes in density due to temperature and salinity distributions are oceanographic vectors. Biota are biological vectors.

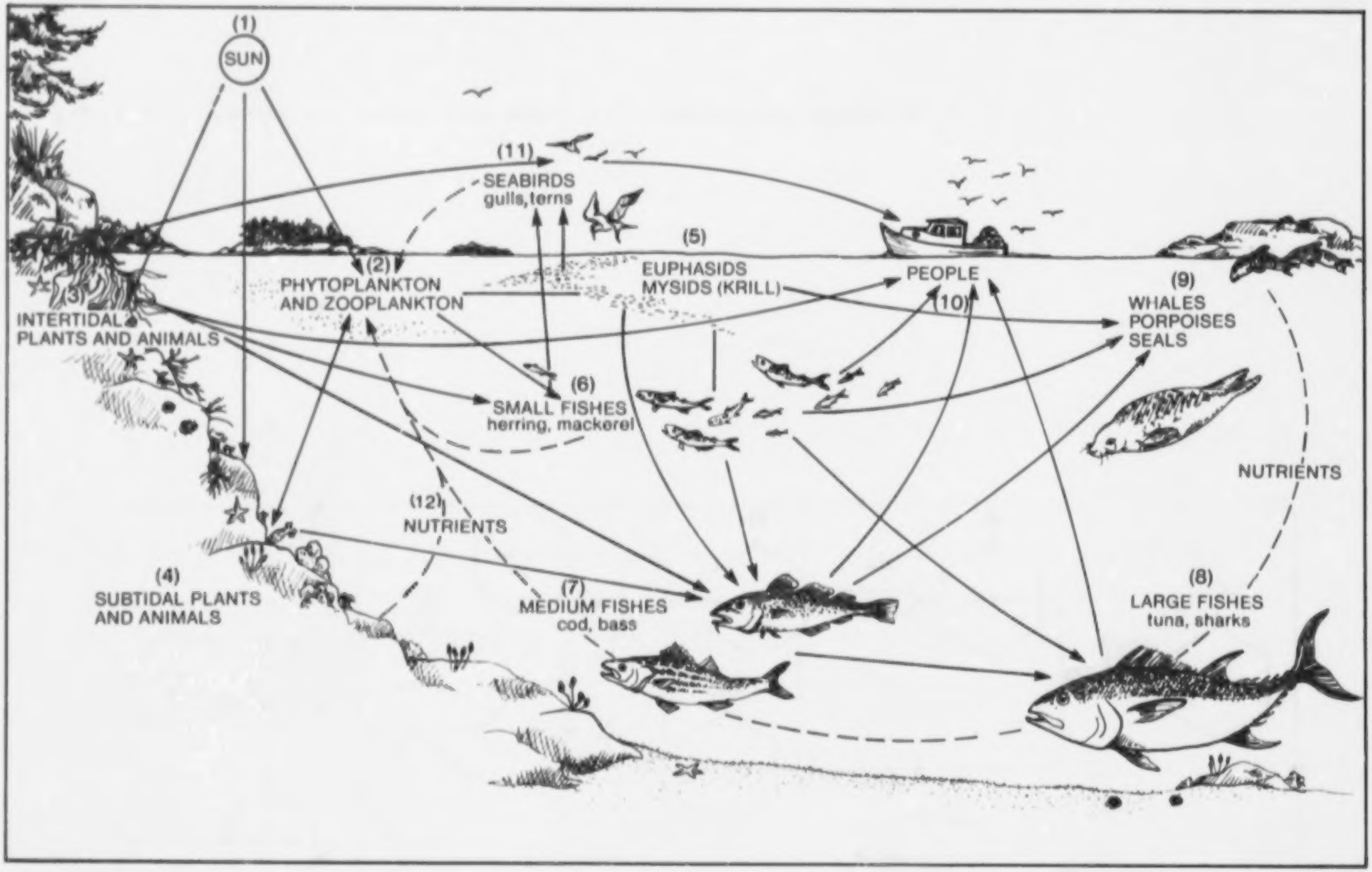

(1)
SUN
(11)
SEABIRDS
gulls, terns
(5)
EUPHASIDS
MYSIDS (KRILL)
PEOPLE
(10)
(2)
PHYTOPLANKTON
AND ZOOPLANKTON
(3)
INTERTIDAL
PLANTS AND ANIMALS
(9)
WHALES
PORPOISES
SEALS
(6)
SMALL FISHES
herring, mackerel
NUTRIENTS
(12)
NUTRIENTS
(4)
SUBTIDAL PLANTS
AND ANIMALS
(7)
MEDIUM FISHES
cod, bass
(8)
LARGE FISHES
tuna, sharks

Figure 1-5. Food web in the marine system of eastern Maine (Maine Research Associates, Ltd. 1978). The solid line shows the direction in which energy flows.

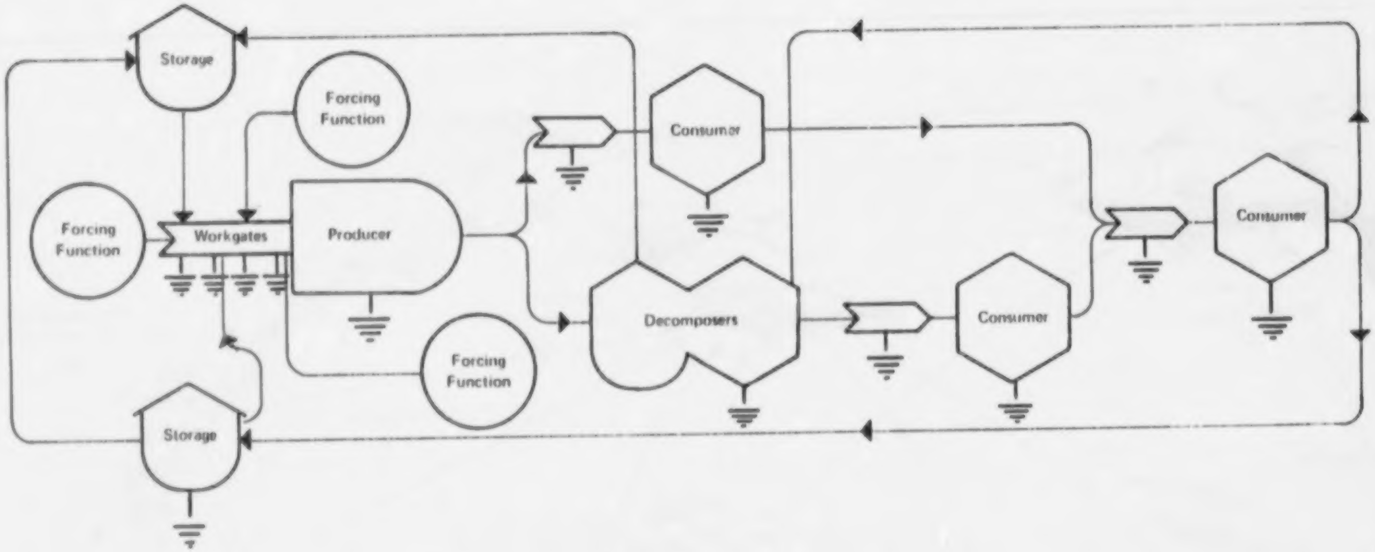

Storage
Forcing Function
Forcing Function
Workgates
Producer
Forcing Function
Storage
Consumer
Decomposers
Consumer
Consumer

Figure 1-6. Conceptual energy flow model for a generalized ecosystem.

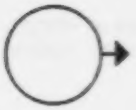
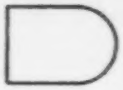
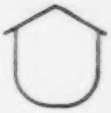
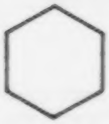
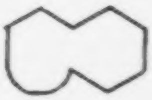
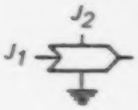
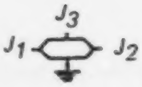
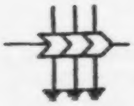
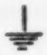
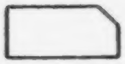
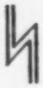
	**Source**	The circular symbol represents a source of energy such as the sun, fossil fuel, or the water from a reservoir. Circular symbols can also represent forcing functions such as tides, geologic events, and climatology.
	**Primary Producer**	The bullet-shaped symbol represents the reception of pure wave energy such as sound, light,and water waves. In this module, energy interacts with some cycling material producing an energy-activated state, which then returns to its deactivated state,passing energy on to the next step in a chain of processes. Green plants, which capture the sun's energy to build carbohydrates from the earth's elements, are an example.
	**Storage Compartment**	The passive storage symbol shows location in a system for passive storage,such as moving potatoes into a grocery store or fuel into a tank. No new potential energy is generated,and some work must be done in the process of moving the potential energy in and out of the storage by some other unit.
	**Consumer**	The hexagonal symbol represents the combination of storage compartment and work gate by which potential energy stored in one or more sites in a subsystem is fed back to do work on the successful processing and work of that unit. Autotrophic animals or consumers are represented by this symbol.
	**Detrital Microbial Complex**	This symbol is a combination of a storage compartment and a consumer compartment. The storage compartment refers to detrital particles, dead pieces of organic material which contain stored energy. The microbial decomposers colonize on the detrital particles and consume the stored energy within the particles for their own growth and maintenance.
	**Work Gate**	The work gate module at which a flow of energy (J_2) makes possible another flow of energy (J_1). This action may be as simple as a person turning a valve, or it may be the interaction of limiting fertilizer in photosynthesis.

Figure 1-7. An explanation of the symbols used in the energy flow model (figure 1-6).

(continued)

Figure 1-7 (continued)

	**Two-way Work Gate**	This symbol represents a two-way module in which the flow of energy (J_2) may proceed in either direction $(J_1$ or $J_2)$ depending upon another function.
	**Sequential Work Gate**	This multiple work gate implies that a variety of energy flow inputs are required for a certain resultant transformation of energy flow to take place.
	**Heat Sink**	A heat sink is required according to the second law of thermodynamics for all processes that are real and spontaneous. All processes deliver some potential energy into heat. Heat is the random wandering of molecules that have kinetic energy, and it is this wandering from a less probable to a more probable state that pulls and drives real processes connected to such flows.
	**Economic Activity**	Economic activity requires a transfer of energy for dollars through a transaction. Economic activity may be thought of as an artificial forcing function imposed by man on a natural system.
	**Migratory Switch**	A migratory switch requires the expenditure of energy for both export and import of energy to the system in the form of migrating animals. Various switches are involved in triggering migrations such as temperature and insolation.

Some nutrients limit growth and reproduction. In estuarine and marine systems, nitrogen availability is of critical importance (see chapters 4 and 5, "The Marine System" and "The Estuarine System"). In palustrine, lacustrine, and riverine systems, phosphorus is a limiting element. The most important biogeochemicals, nutrients (nitrogen and phosphorus) and organic matter, are discussed in the systems chapters (4 through 10).

People affect the distribution and content of materials in systems through inputs of water pollutants (industrial and municiapl wastes, domestic animal manure, agricultural fertilizers, pesticides, herbicides, heavy metals, and oil), atmospheric pollutants (SO_2 and NO_2, which cause acid rains), habitat alteration (e.g., construction of causeways in estuarine areas, which alters tidal flow, flushing rates, and, therefore, concentrations of nutrients), and by extracting or harvesting nutrients and other components (water, peat, fish, and birds) of the system. These impacts are discussed in chapter 3, "Human Impacts on the Ecosystem."

Biota

The biotic (living) component of an ecosystem is composed of a diverse group of organisms that live in a variety of physical habitats. The biotic community has three basic components: producers, consumers, and decomposers.

Producers are autotrophic organisms that manufacture food from inorganic substances using energy from the sun. All green plants are producers. In the Gulf of Maine, phytoplankton are the major producers, while in nearshore marine waters and in estuarine systems macroalgae and intertidal emergent plants are also important. Nonpersistent rooted aquatic submergents (e.g., pond weeds), emergents (e.g., pickerel weed), and phytoplankton are important producers in the lacustrine and riverine systems. Producers in the palustrine system in coastal Maine include persistent nonvascular (e.g., mosses and liverworts) and vascular plants (emergent herbs, shrubs, and trees). In the terrestrial system vascular plants dominate.

Generally, three consumer levels are present in any system. In coastal Maine, primary consumers in aquatic environments are represented by the herbivorous zooplankton, benthos, birds, and fish, and in terrestrial systems by insects, certain mammals (e.g., hares and hoofed mammals) and birds (e.g., geese and finches). Secondary consumers (or carnivores) in Maine include certain waterfowl, other birds, mammals, fish, and predaceous insects. Tertiary consumers are carnivores that feed upon primary and secondary consumers. Large predatory birds (bald eagles and osprey), mammals (bobcats, harbor seals, and people), and fish (Atlantic cod and Atlantic salmon), are examples of tertiary level consumers in coastal Maine. Tertiary consumers usually have relatively less biomass available to them as prey, exhibit greater mobility, have larger home ranges, and require a greater diversity of habitat than primary or secondary consumers.

Variations in these feeding habits also exist. Omnivores consume both plant and animal material. Scavengers eat dead organic matter, for example, carrion and refuse.

In the Maine coast ecosystem, the decomposers are fungi, heterotrophic bacteria, and certain insects and other invertebrates. Decomposers process plant and animal tissue, releasing compounds for reuse by plants, and convert and store pollutants. Insects and certain aquatic invertebrates process detritus and are themselves utilized as food in the system.

People affect the biota directly through activities that (1) alter the habitat in which a species lives thereby impacting its population; (2) impact food webs (through input into the ecosystem of heavy metals, biocides, and oil), energy flows (e.g., siltation and obstruction of water flow), and biogeochemical cycles (nutrient depletion and eutrophication); and (3) result in the harvest of certain species (commercial fishing and shellfish harvest, sport fishing, hunting, trapping, and timber harvesting).

The composition, distribution, and functional requirements of biota are discussed by system in this characterization and detailed information can be found in the chapters on the various systems (chapters 4 through 10). In addition, chapters 11 through 20 present information on commercially and ecologically important groups of species. Common names of species are used in the text except where more than one or no common name exists. Taxonomic names of most plants and invertebrates are given in the text to avoid ambiguity. The taxonomic names of all species mentioned in the text are listed in the appendix.

Abiota

The ecosystem of the Maine coast is dominated by its physical components, for example, geology, climate, and hydrology. The geological and hydrological forces form the physical structure to which the biotic components must adapt. Geology and hydrology interact to determine the distribution and chemistry of surface and ground waters (figure 1-8). Water circulates from the oceans to the atmosphere and back to the oceans, either directly or via terrestrial and/or aquatic systems, and transports life-supporting elements that are released from rocks and soils by weathering.

Climate interfaces with both geology and hydrology and is a dominant forcing function in Maine. The climatic factors of precipitation, temperature, insolation, fog, storms, wind, humidity, and ice all affect the abundance and distribution of biota.

People place stress on the abiotic aspects of the ecosystem through socioeconomic activities. The characteristic features of these forcing functions in coastal Maine are detailed in chapter 2, "The Maine Coast Ecosystem."

THE SPECIES POPULATIONS

Major groups of species on the Maine coast are listed in figure 1-9. Species populations, including those of commercially and ecologically important species, and their interrelationships are discussed in chapters 11 through 20. The seasonal status and distribution of groups of species, uses of habitat, various life stages, reproduction, feeding habits, importance to humanity, factors of abundance (natural and artificial), and management are examined. Detailed studies of important species are included.

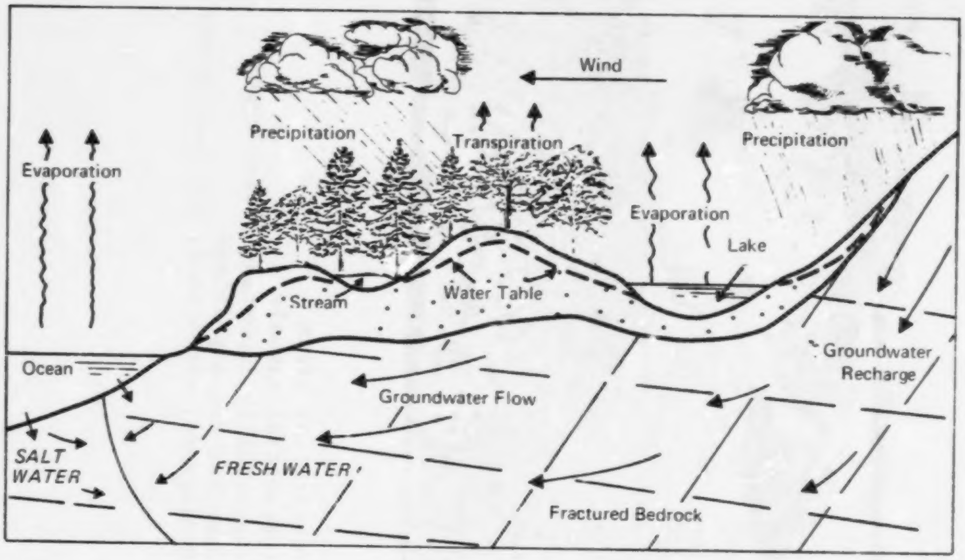
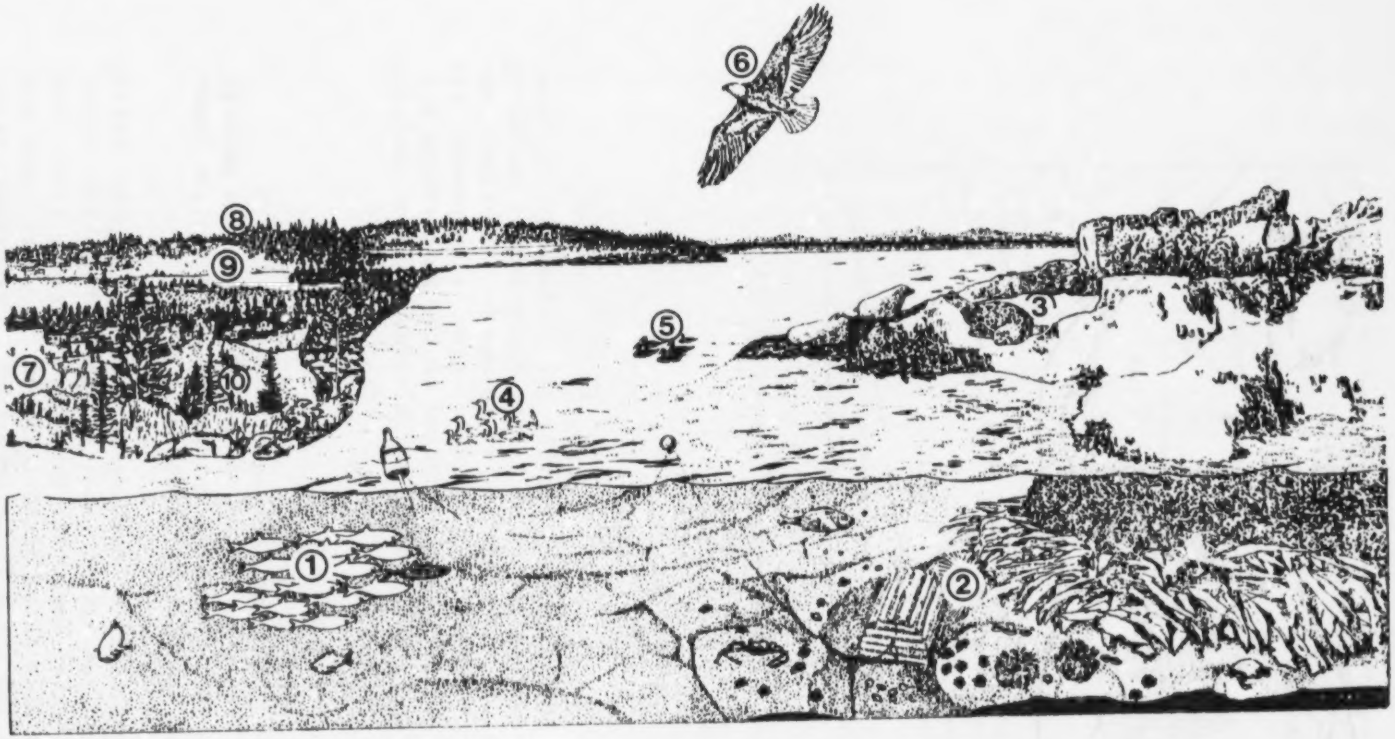

Wind
Precipitation
Transpiration
Precipitation
Evaporation
Evaporation
Lake
Stream
Water Table
Ocean
Groundwater Recharge
Groundwater Flow
SALT WATER
FRESH WATER
Fractured Bedrock

Figure 1-8. The hydrological cycle (adapted from Caswell 1977).

ORGANIZATION OF INFORMATION

Appendices to each chapter are grouped together in volume 4. A cross-referenced list of information sources pertinent to the Maine coast, including those used in this characterization, is contained in volume 5. An atlas, containing maps of each region at a scale of 1:24,000, also accompanies the characterization (volume 6). These maps are based on the most recent U.S. Geological Survey orthophotoquads. Four classes of information are included on the maps:

1. National Wetlands Inventory Data.
2. Land Cover Types (vegetative cover).
3. Geological, Physical, and Land Use Features.
   Significant geologic features, surveyed peat bogs, marine geology, mines and mineral prospects, quarries, watersheds, conservation lands, point pollution sources, and natural landmarks.
4. Fish and Wildlife
   Shellfish, marine worms, eagle nesting territories, osprey nesting sites, important seal haulout sites, important seabird nesting areas, wading bird nesting areas, important shorebird roosting areas, anadromous and catadromous fish runs, historical herring weirs, deer wintering areas, wetlands and tidal flats important to waterfowl, existing dam sites, fishway locations, State designated critical areas, rare plant locations and locations of coastal plateau bogs.



1. Finfish
2. Commerically important invertebrates
3. Marine mammals
4. Waterbirds
5. Waterfowl
6. Terrestrial birds
7. Terrestrial mammals
8. Commercially important forest types
9. Reptiles and amphibians
10. Endangered, threatened, and rare plants

Figure 1-9. Major groups of species of the Maine coast.

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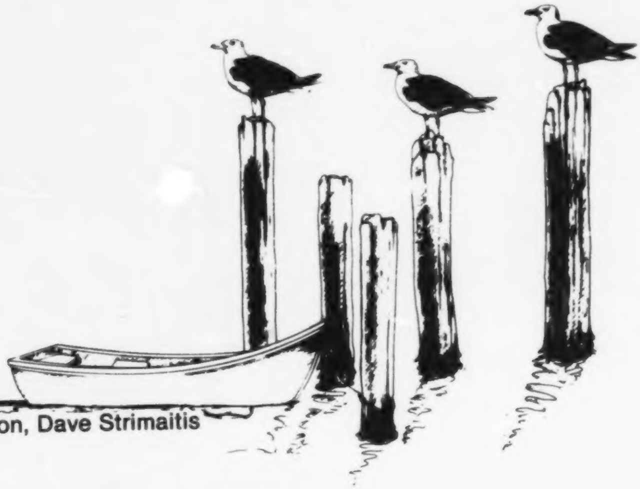
Chapter 2
The Coastal Maine Ecosystem



Authors: Stewart Fefer, Edward Shenton, Barry Timson, Dave Strimaitis

The 300-foot (91.4 m) isobath in the Gulf of Maine and the inland limits of the townships that enclose tidal waters are the boundaries of the characterization area (T8SD, T9SD, T10SD, and Marion townships do not enclose tidal waters but are included in the characterization area because they are in close proximity to saline waters and are influenced by coastal processes). The characterization area will be referred to also as the coast of Maine, coastal Maine, and the coastal zone. The offshore and inland boundaries are separated by distances ranging from 20 miles (32 km) to 90 miles (144 km) and encompass an area of about 3740 sq mi (9686 km), excluding nearshore subtidal marine waters.

GEOGRAPHY

A diverse mixture of wetlands, uplands, and open water, the Maine coast is characterized by extensive areas of rocky shores, mudflats, large embayments, ericaceous bogs, and coniferous forests. Approximately 1.8 million acres (729,455 ha) of the coast is upland habitat and 563,766 acres (228,262 ha) are wetlands. Palustrine wetlands comprise the largest area of any of the aquatic systems (189,702 acres; 76,819 ha; 34%), followed by the marine (170,313 acres; 68,953 ha; 30%) and estuarine systems (130,076; 52,662 ha; 23%). Lacustrine wetlands systems comprise 57,537 acres (10%), and riverine systems 16,137 acres (6533 ha; 3%; table 2-1).

The terrestrial habitat is dominated by forests (85% of the land area) and includes 9% developed land and 4% agricultural land. The types and acreages of wetland systems and classes in each of the regions and towns in the characterization area are listed in appendix A. Maps of the habitats of each region are included in the atlas. The six regions of the characterization area are described briefly below.

Table 2-1. Acreage and Percentage Contribution (parentheses) of Wetland Systems and Subsystems to the Wetland Habitat in the Characterization Area, by Region.

Region	Total wetlands	Palustrine	Lacustrine	Marine		Estuarine		Riverine		
				Subtidal	Inter-tidal	Subtidal	Inter-tidal	Tidal	Lower perennial	Upper perennial
1 %	45,716.4 (100)	7096.1 (15.5)	425.7 (.9)	11,714.6 (25.6)	11,259.7 (24.6)	5907.8 (12.9)	8189.6 (18)	882.4 (1.9)	119.3 (.3)	121.2 (.3)
2 %	77,287.6 (100)	24,174.9 (31.2)	4199.2 (5.4)	2323.0 (3.0)	1540.0 (2.0)	18,710.7 (24.2)	14,708.0 (19.0)	11,140.1 (14.4)	353.4 (.5)	138.3 (.2)
3 %	49,296.2 (100)	19,348.5 (39.2)	7218.7 (14.6)	988.4 (2.0)	3441.6 (7.0)	10,381.9 (21.1)	7736.6 (15.7)	0 (0)	163.4 (.3)	17.1 (.03)
4 %	130,218.7 (100)	40,303.5 (30.9)	12,900.1 (9.9)	40,167.3 (30.8)	15,887.2 (12.2)	10,709.0 (8.2)	8980.5 (6.9)	871.2 (.7)	175.3 (.1)	224.6 (.2)
5 %	116,035.1 (100)	40,988.8 (35.3)	19,567.1 (16.8)	25,180.3 (21.7)	13,279.0 (11.4)	6820.0 (5.9)	9826.4 (8.5)	0 (0)	370.7 (.3)	2.8 (.002)
6 %	145,252.2 (100)	57,830.7 (39.8)	13,226.4 (8.9)	29,775.2 (20.5)	14,756.7 (10.2)	14,162.9 (9.7)	13,942.9 (9.6)	297.6 (.2)	725.2 (.5)	534.6 (.4)
Total %	563,806.2 (100)	189,742.5 (33.6)	57.537.2 (10.2)	110,148.8 (19.5)	60,164.2 (10.7)	66,692.3 (11.8)	63,384.0 (11.2)	13,191.3 (2.3)	1907.3 (.3)	1038.6 (.2)

Region 1

This region is the westernmost region in the characterization area. It consists of approximately 250 miles (300 km) of shoreline (Casco Bay) and 167,330 acres (66,932 ha) of upland and fresh water. It has less freshwater wetland than any of the other regions (table 2-1). The abundance and quality of the intertidal habitat make the marine and estuarine environment of this region important. The presence of many large shallow bays with intertidal flats, mussel reefs, and eelgrass beds provide large acreages of many habitats. Similarly, the occurrence of many nearshore islands (approximately 400) provide additional intertidal areas, as well as island habitats for nesting waterbirds and rocky ledges for seals.

Forests in region 1 are dominated by white pine, pitch pine, oak, and other hardwoods. Its terrestrial habitat includes a larger proportion of developed land than other regions. This region is the most densely populated in the characterization area. Portland is the largest port in Maine and has the largest fish landings. The major oil shipping terminal in Maine is also in Portland.

Region 1 includes nine coastal towns in Cumberland County (see figure 2-1 and appendix B).

Region 2

Region 2 contains approximately 650 miles (1040 km) of shoreline and 319,100 acres (127,640 ha) of upland and fresh water. It has a greater proportion of estuarine and riverine tidal wetland than any other region (table 2-1). It includes the estuaries of three major rivers, the Kennebec, Androscoggin, and Sheepscot. This region contains what is in some ways the most unique shoreline on Maine's diverse coast. The rolling, hilly terrain and drowned river mouths produce a deeply indented, steep-sided, fjord-like coast. The southward projecting fingers of land are often cut off from the mainland by narrow guts and/or channels. Some areas are shallow, with extensive mud flats, others are steep-sided, with navigable water at low tide. This region also includes the greatest acreage of estuarine emergent wetland and the greatest acreage of sand beaches among the regions. Region 2 encompasses Merrymeeting Bay, a large freshwater tidal bay formed by the confluence of the Kennebec, Androscoggin, Eastern, Cathance, Muddy, and Abagadasset Rivers. The bay itself comprises about 8400 acres (3400 ha), with approximately 99 miles (158 km) of shoreline. It is the largest freshwater tidal bay north of Chesapeake Bay. The bay area is used extensively by migratory waterfowl. The island complex in this region, like that in region 1, is important for migratory, wintering, and breeding seabirds and waterfowl.

The uplands of region 2 are a mosaic of forests, pasture lands, and cultivated fields, as well as developed areas. Forests in this region are predominantly white pine-pitch pine and spruce-fir near the immediate coast and white pine, beech, birch, and maple inland. Many features of historic, scenic, and/or natural interest are present in region 2, a fact which is reflected in the importance of tourism in the local economy. Most of the coastal towns in this region have summer populations two or more times greater than the resident population. Region 2 is the site of Maine's only nuclear power plant, The

Maine Yankee Power Company, located on the Sheepscot estuary in Wiscasset. Boothbay Harbor in this region is a major port for fish landing.

Statutory divisions within region 2 include Sagadahoc County and parts of Cumberland, Lincoln, and Kennebec Counties, which encompass 26 towns (see figure 2-2 and appendix B).

Region 3

This region contains approximately 550 miles (880 km) of shoreline and 188,592 acres (75,436 ha) of upland and fresh water. Region 3 includes a relatively large proportion of estuarine habitat, including the Damariscotta, Medomak, and St. George estuaries and Muscongus Bay. Rocky shorelines are a conspicuous feature of this region. Islands are a dominant, physiographic aspect of Muscongus Bay, which is an important nesting area for waterbirds.

The terrestrial habitat of the region is similar to the eastern portion of region 2. The predominant forest types are spruce-fir along the immediate coast and a mixture of pine, hemlock, spruce, and hardwoods in the interior parts of the region. Industry in this area is dominated by tourism. This region includes 13 towns of Knox County (see figure 2-3 and appendix B).

Region 4

This region consists of approximately 1050 miles (1680 km) of shoreline and approximately 559,075 acres (223,630 ha) of upland and fresh water. It is the largest of the regions and also has the longest shoreline. Penobscot Bay dominates this region. The bay contains a wide variety of marine and estuarine habitats, as well as a large number of islands, and, for these reasons, it is the most important waterbird breeding area on the coast. The topography of this region is varied. A number of small mountains rise from the coastline (Camden Hills and Blue Hill). The upland is characterized by spruce-fir, white pine, and mixed hardwood forests.

The inland portion of this region contains the urban-suburban areas of Bangor and Brewer, which are sharply contrasted by natural areas on the coast, such as Isle au Haut in Penobscot Bay. Tourism also is an important part of the economy of this region. Rockland is the major fish landing port in this region.

Region 4 encompasses parts of Knox, Waldo, Penobscot, and Hancock Counties and includes 34 towns (see figure 2-4 and appendix B).

Region 5

This region occupies 650 miles (1040 km) of shoreline and 422,615 acres (169,046 ha) of upland and fresh water. It is perhaps the most scenic region of the Maine coast. Acadia National Park on Mt. Desert Island attracts 2.5 to 3.0 million tourists annually.

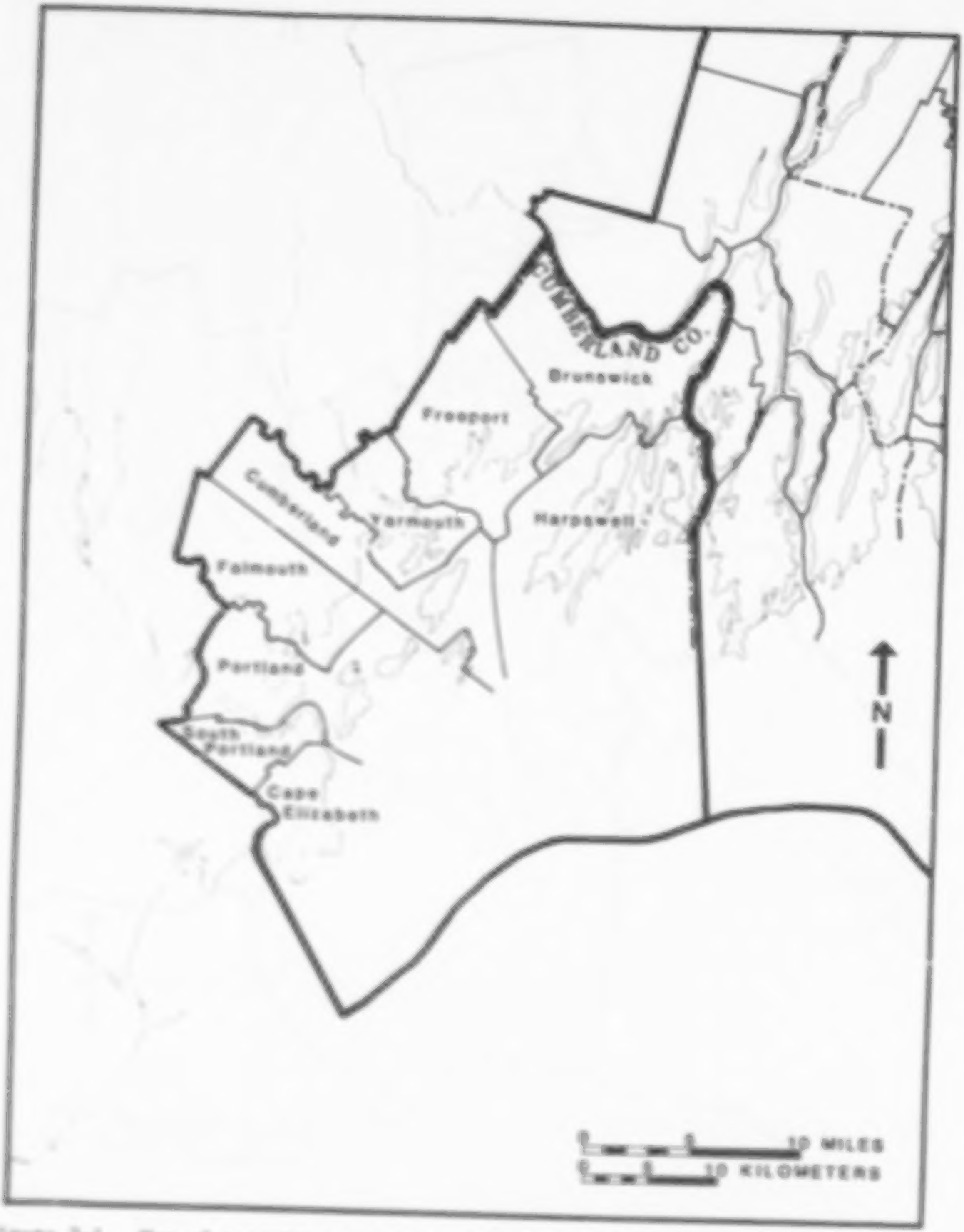

CUMBERLAND CO.
Brunswick
Freeport
Cumberland
Yarmouth
Harpswell
Falmouth
Portland
1
South Portland
Cape Elizabeth
N
0 5 10 MILES
0 5 10 KILOMETERS

Figure 2-1. Map of townships in Region 1 in the characterization area.

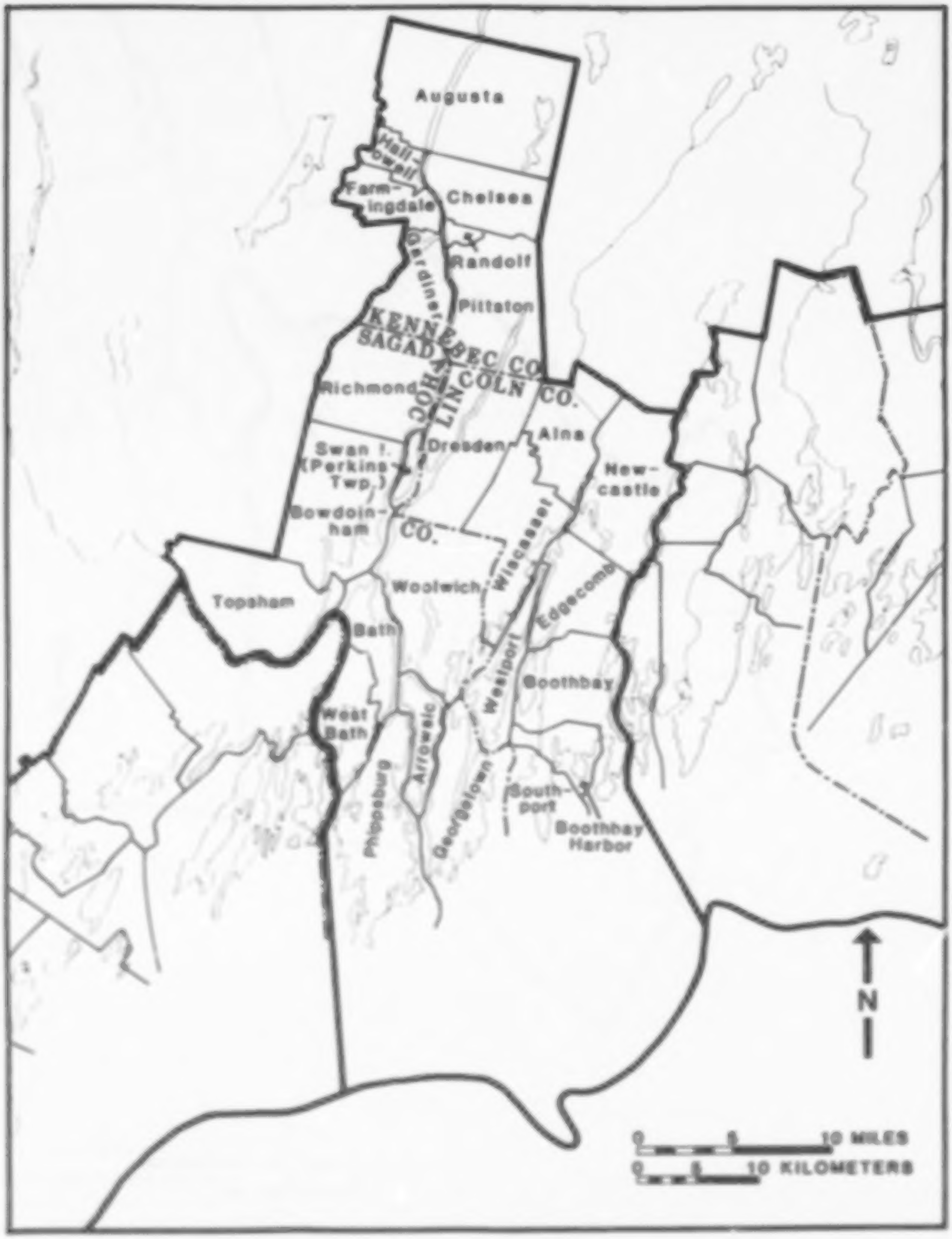

Augusta
Hallowell
Farmingdale
Chelsea
Gardiner
Randolf
Pittston
KENNEBEC CO.
SAGADAHOC CO.
LINCOLN CO.
Richmond
Swan I. (Perkins Twp.)
Dresden
Alna
Newcastle
Bowdoinham
Woolwich
Wiscasset
Topsham
Bath
Edgecomb
Westport
Boothbay
West Bath
Arrowsic
Phippsburg
Georgetown
Southport
Boothbay Harbor
N
0 5 10 MILES
0 5 10 KILOMETERS

Figure 2-2. Map of townships in Region 2 in the characterization area.

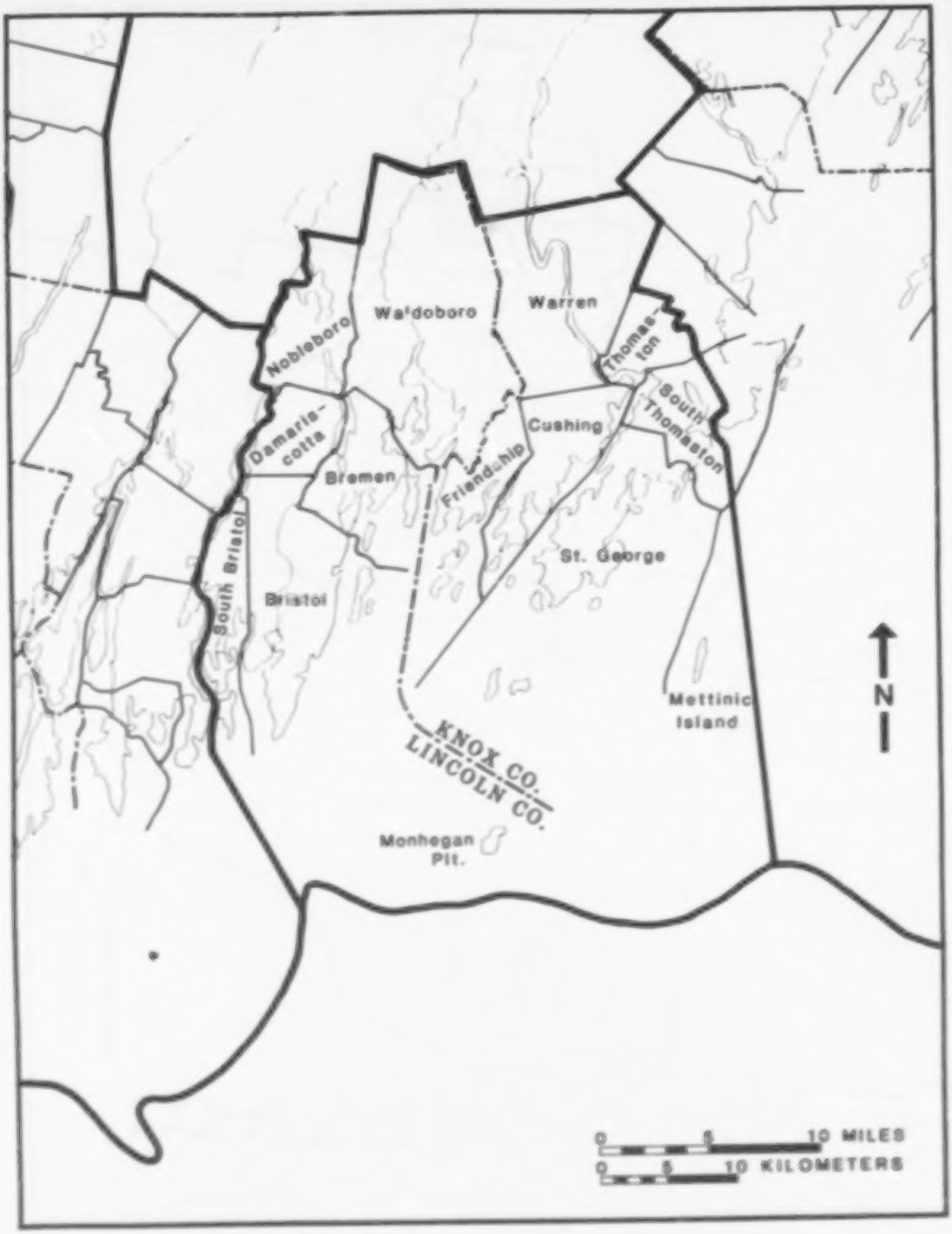

Nobleboro
Waldoboro
Warren
Thomaston
South Thomaston
Damariscotta
Cushing
Bremen
Friendship
South Bristol
Bristol
St. George
Mettinic Island
KNOX CO.
LINCOLN CO.
Monhegan Plt.
N
0 5 10 MILES
0 5 10 KILOMETERS

Figure 2-3. Map of townships in Region 3 in the characterization area.

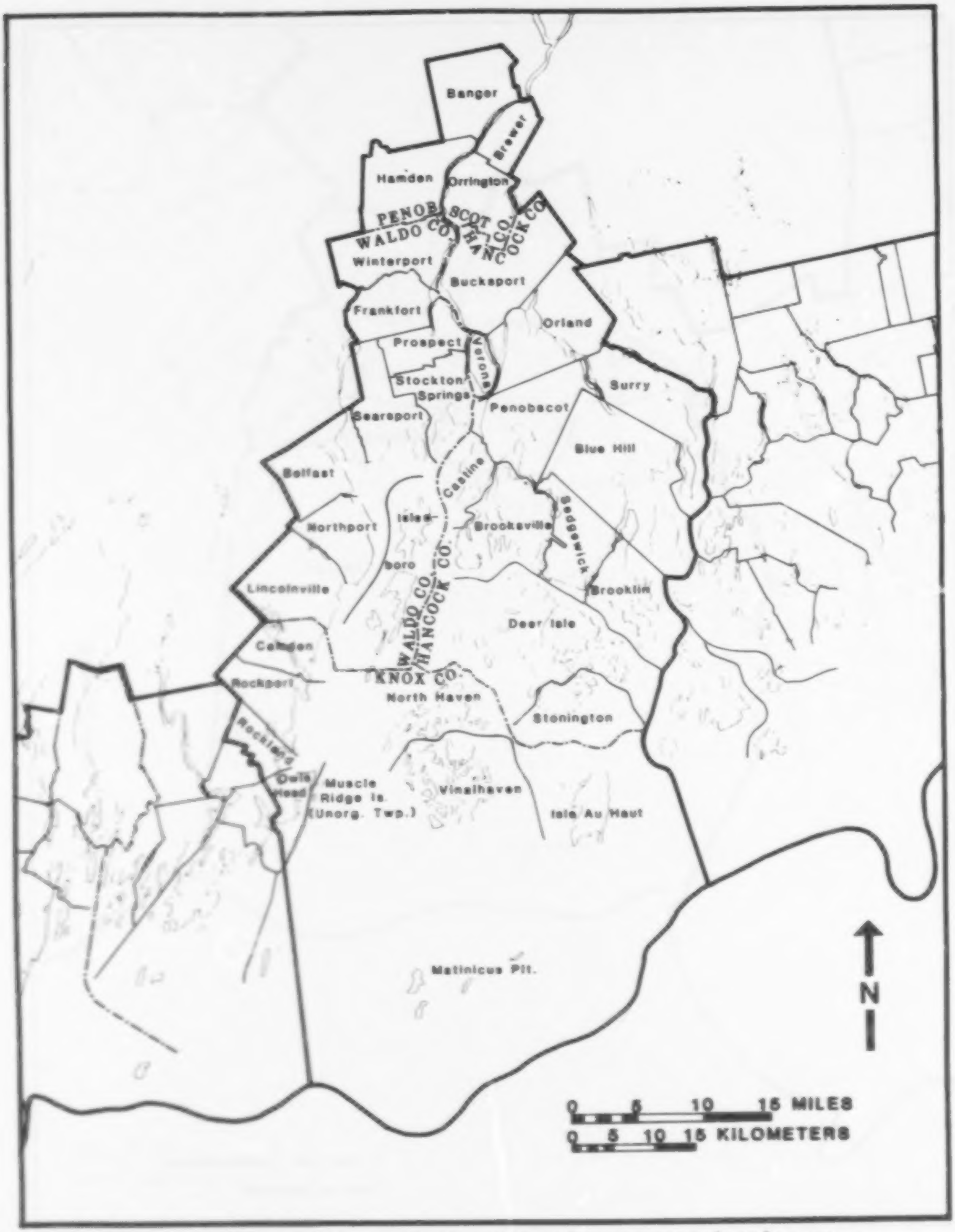

Bangor
Brewer
Hamden
Orrington
PENOBSCOT CO.
HANCOCK CO.
WALDO CO.
Winterport
Bucksport
Frankfort
Orland
Prospect
Verona
Stockton Springs
Searsport
Penobscot
Surry
Belfast
Blue Hill
Castine
Isles-
boro
Northport
Brooksville
Sedgwick
Lincolnville
Brooklin
Deer Isle
Camden
WALDO CO.
HANCOCK CO.
KNOX CO.
Rockport
North Haven
Stonington
Rockland
Owls Head
Muscle Ridge Is. (Unorg. Twp.)
Vinalhaven
Isle Au Haut
Matinicus Plt.
N
0 5 10 15 MILES
0 5 10 15 KILOMETERS

Figure 2-4. Map of townships in Region 4 in the characterization area.

The Narraguagus River is the largest in the region. Narraguagus Bay is characterized by a higly irregular shoreline, extensive intertidal flats, and many islands. Uplands near the coast are dominated by spruce-fir and mixed forests, while hardwood, mixed forests, and barrens dominate the inland area. This region has extensive intertidal flats, which are important for shellfish, to migratory shorebirds, and wintering black ducks. This region includes part of Hancock and Washington Counties and encompasses 25 towns (see figure 2-5 and appendix B).

Region 6

This is the easternmost region on the coast, consisting of 700 miles (1120 km) of shoreline and 436,236 acres (174,494 ha) of upland and fresh water. This region includes the largest amount of intertidal marine and estuarine habitats including extensive flats and estuarine emergent wetlands (the latter associated primarily with the Machias and Pleasant River estuaries). The coastline along the western portions of this region is highly irregular, with many bays, coves, islands, and estuaries. From Little Machias Bay (Cutler) east to Lubec the coast is bold, rock-bound and, for Maine, fairly regular. Migratory whales and seabirds are common to this area. From West Quoddy Head through Cobscook Bay and northward to Calais, the tidal range may exceed 20 feet, 6 m, (22.8 feet, 7 m, at Calais). Within this area, the Cobscook Bay complex of inlets, tidal creeks, and rivers in combination with strong tidal flows create many areas of unique habitat. The extensive intertidal flats in this region provide excellent habitat for shellfish and other invertebrates, shorebirds, and black ducks.

The upland habitat is characterized by a low density human population, with minimal industrial development relative to other areas of the coast. It is dominated by spruce-fir forests, which play a major role in the coastal economy. Eastport is the major fish landing port in this region.

Region 6 encompasses 24 Washington County towns (see figure 2-6 and appendix B).

FORCING FUNCTIONS

The geography and habitats of coastal Maine result from the complex interaction of geological, hydrological, and meteorological forces over centuries. The socioeconomic activities of people are a powerful and relatively recent forcing function. These forcing functions are examined below.

Climate

Coastal Maine has a northern temperate climate with sufficient rainfall to support large forests, extensive agriculture, and abundant fish and wildlife resources. Mean annual temperature is approximately 44°F (7°C) and extremes range from 100 to -30°F (38 to -34°C). Mean annual precipitation is 44 inches (112 cm) and monthly rainfall ranges usually between 3 and 5 inches (8 to 13 cm).

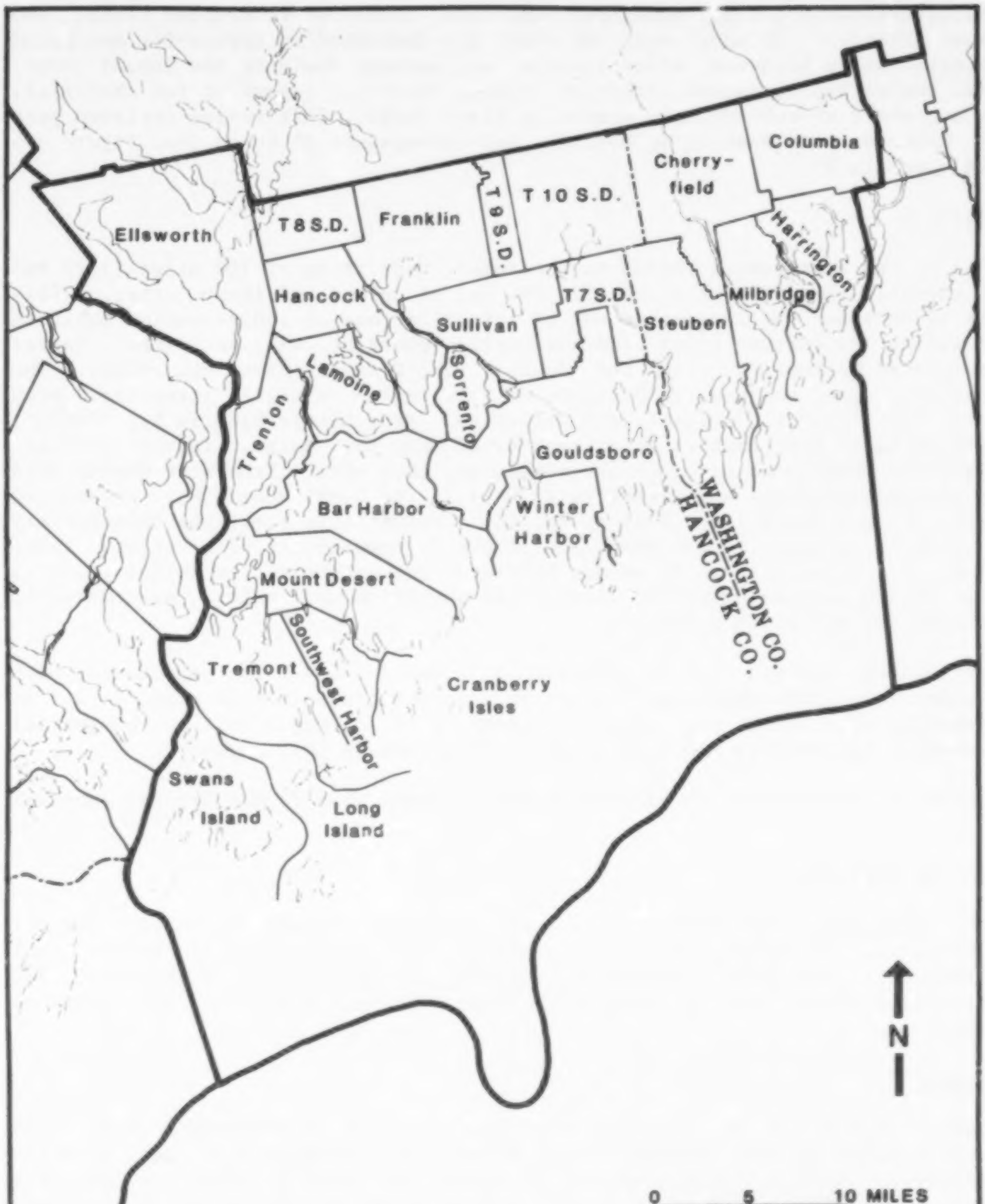

Columbia
Cherry-field
T 10 S.D.
T 9 S.D.
Franklin
T 8 S.D.
Ellsworth
Harrington
Milbridge
Hancock
Sullivan
T 7 S.D.
Steuben
Lamoine
Sorrento
Trenton
Gouldsboro
Bar Harbor
Winter Harbor
WASHINGTON CO.
HANCOCK CO.
Mount Desert
Southwest Harbor
Tremont
Cranberry Isles
Swans Island
Long Island
N
0 5 10 MILES
0 5 10 KILOMETERS

Figure 2-5. Map of townships in Region 5 in the characterization area.

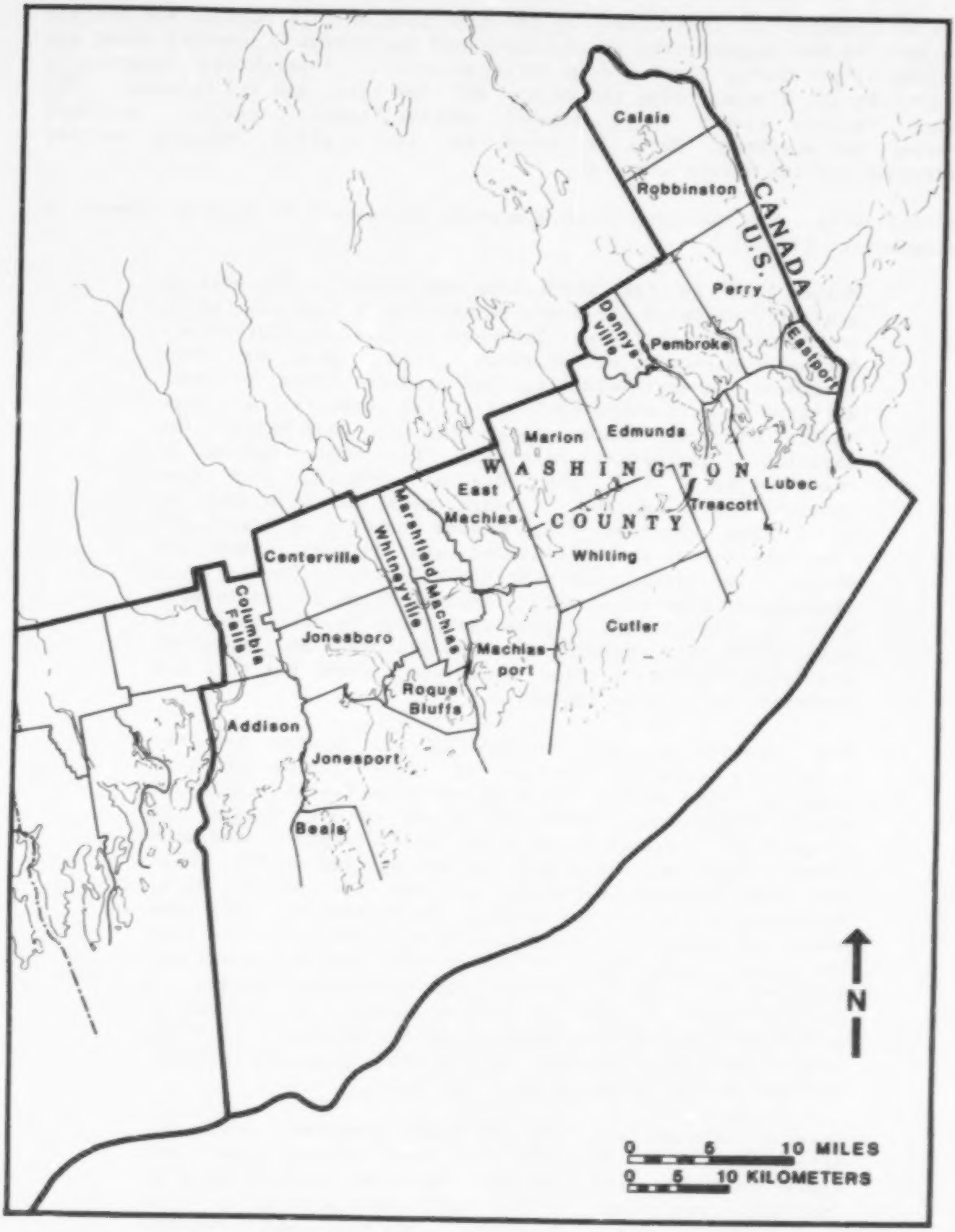

Calais
Robbinston
CANADA
U.S.
Perry
Dennysville
Pembroke
Eastport
Marion
Edmunds
WASHINGTON
COUNTY
Lubec
Trescott
East Machias
Whiting
Marshfield
Whitneyville
Machias
Centerville
Columbia Falls
Jonesboro
Cutler
Machiasport
Roque Bluffs
Addison
Jonesport
Beals
N
0 5 10 MILES
0 5 10 KILOMETERS

Figure 2-6. Map of townships in Region 6 in the characterization area.

Maine's climate is controlled by the same factors that control the weather over much of New England, but temperatures and humidities of coastal areas are modified by air masses flowing from offshore waters. A particular location is affected by its distance from the ocean, its elevation, and its terrain. The latter factors create three natural weather zones: coastal, southern interior, and northern. Maine is noted for its rapidly changing weather conditions and its severe winters.

The following are excerpts from a general discussion of Maine's climate by Lautzenheiser (1972):

> Maine lies in the "prevailing westerlies" - the belt of generally eastward air movement which encircles the globe in the middle latitudes. Embedded in this circulation are extensive masses of air originating in higher or lower latitudes and interacting to produce storm systems. Relative to most other sections of the country, a large number of such storms pass over or near Maine. The majority of air masses affecting this State belong to three types: (1) cold, dry air pouring down from subarctic North America, (2) warm, moist air streaming up on a long overland journey from the Gulf of Mexico and from subtropical waters eastward, and (3) cool, damp air moving in from the North Atlantic. Because the atmospheric flow is usually offshore, Maine is influenced more by the first 2 types than it is by the third. In other words, the adjacent ocean constitutes an important modifying factor on the immediate coast, but does not dominate the climate statewide.
>
> The procession of contrasting air masses and the relatively frequent passage of storms bring about a roughly twice-weekly alternation from fair to cloudy or stormy conditions, attended by often abrupt changes in temperature, moisture, sunshine, wind direction, and wind speed. (However, there are) periods of time during which the same weather patterns continue for several days, infrequently for several weeks. (Consequently,) the same month or season will exhibit varying characteristics over the years - sometimes in close alternation, sometimes arranged in similar groups for successive years. A "normal" month, season, or year is indeed the exception rather than the rule....Hence, "weather averages" in Maine usually are not sufficient for important planning purposes without further climatological analysis.
>
> Coastal storms or "northeasters" sometimes seriously affect the coast. They generate very strong winds and heavy rain or snow, and they sometimes produce glaze or "ice storm conditions." They can produce abnormally high wind-driven tides, affecting beaches and coastal installations. In winter, these storms produce some of the heavier snowfalls along the coast. Occasionally, in summer or fall, a storm of tropical origin affects Maine.

> Usually the storm will be similar to the northeasters. But a few such storms may retain near or full hurricane force....Fortunately, storms of tropical origin do not affect Maine at all in most years. Two or more storms in 1 year should be expected about 1 year in 20.

Summarized climate statistics at stations within or near the characterization area follow. Data on the five basic climatic parameters, precipitation, temperature, cloudiness, wind, and relative humidity, are compared. Climatic features such as fog, snow, ice, and storms are reviewed. Most data used have been drawn from U.S. Government publications.

Information on the climate of coastal Maine has been assembled from data gathered at 14 stations identified in figure 2-7. At least 30 years of records underlie the data summaries of the majority of these stations [U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) irregular]. Data on precipitation and temperature are complete and available throughout the characterization area. A summary of mean temperature and total precipitation for approximately the last 30 years is given in table 2-2.

Precipitation is generally greatest along the coast, mainly at Rockland, Bar Harbor, and Machias. Eastport and Portland, which are also on the coast, have less rainfall, however, so local conditions must account for some of the variability. The range between the lowest (40.7 inches; 103 cm) and highest (48.9 inches; 124 cm) precipitation totals is about 8 inches (20 cm) or approximately 15% to 20% of the total.

Average temperatures show slightly less variability, ranging from 41.8°F (5.4°C) at Old Town to 46.0°F (7.7°C) at Rockland. Here much of the variability is related to the station's distance from the coast, or northward location. The coldest station is located well inland at Old Town, while the next coldest stations are in region 6 at Eastport, Woodland, and Machias.

More information on the characteristics of basic climate parameters can be gained from comparing the annual pattern of monthly means. Figures 2-8 and 2-9 show the distribution of cloudiness, temperature, humidity, and precipitation at Portland and Eastport. The only evaporation measurements recorded near the coast were taken at New Gloucester and are therefore more representative of Portland than Eastport. It is expected that the evaporation pattern exhibited at New Gloucester will be similar at Eastport, although the magnitude will differ.

Monthly mean temperature. Monthly temperature distributions in figures 2-8 and 2-9 show the range between mean high and low temperatures and the record high and low temperatures observed at Eastport and Portland respectively during the 30-year period. The marine influence appears to be strongest in moderating the record low temperatures at Eastport during winter. Otherwise, mean low temperatures at Eastport would be about 5 to 15°F (3 to 8 °C) cooler and mean high temperatures would be 0 to 8°F (0 to 4°C) cooler than those at Portland, because of Eastport's northward location. The average temperature at Eastport is 2 °F (1 °C) cooler than the average temperature at Portland (table 2-2). Temperature distributions at other stations in the coastal zone are given in figure 2-10. Modest differences between coastal and inland areas are discernable, in addition to the temperature decline from south to north.

Monthly mean precipitation. Monthly precipitation means at Portland and Eastport show that no dry or wet season exists (figures 2-8 and 2-9). The most prominent feature of the distributions is a relative maximum that occurs in late fall, preceded by a relative minimum in midsummer. Monthly means are between 3 and 4 inches (8 to 10 cm).

This precipitation pattern is general to the coastal zone. Distributions at other stations are given by region in figure 2-11. Minor variations in pattern and magnitude are not systematic and appear to be the result of either local effects or variations in the length of record. Distributions of the number of days per month with precipitation 0.1 inch are virtually constant from station to station. Significant precipitation occurs during an average of 6 to 8 days/month, with weak maxima in early spring and late fall.

While the average precipitation distribution favors particular months, it should be emphasized that the wettest month in any particular year could be any one of several. Variations in total annual precipitation seldom exceed 30% of the average and severe drought is very rare. Nonetheless, short dry spells are common, usually occurring in the warmer summer months.

Cloud occurrence. Cloudiness is classified as either "cloudy" (80% to 100% cloud cover), "partly cloudy" (40% to 70% cloud cover), or "clear" (0% to 30% cloud cover). Cloudiness is measured during daylight hours only. In Maine, cloudiness is nearly evenly divided among the three categories, with cloudy conditions more prevalent at both Eastport and Portland (figures 2-8 and 2-9). Maine has no true dry or wet season, because of its location within the midlatitude storm track. The clearest skies occur in midsummer and the cloudiest in late fall. At Portland an additional cloud maximum occurs in early spring. A cloud maximum of lesser magnitude occurs at this time at Eastport. These data are consistent with the monthly precipitation records. Eastport has fewer hours of cloudy skies and more hours of partly cloudy skies in spring than Portland and, therefore, it appears that Eastport lies on the northern fringe of many spring storms that pass through Portland.

Evaporation and relative humidity. Evaporation data are collected only during May through October. As previously stated, the data shown in figures 2-8 and 2-9 are for New Gloucester (U.S. Department of Commerce 1963 to 1976) and therefore are more representative of conditions at Portland than those at Eastport. The data indicate that the months of greatest evaporation are in midsummer, as might be expected. Total evaporation over the 6-month period in the 14-year record averages about 30 inches (76 cm), or approximately two-thirds of the total annual precipitation in the coastal region. Average precipitation near Portland over the same 6 months totals about 18.5 inches (47 cm) in the 30-year record. Periods with high temperatures, high evaporation rates, and low rainfall sometimes necessitate agricultural irrigation. The risk of fires in fields and forests also rises at this time, because of the increased frequency of thunderstorms.

Table 2-2. Mean Temperature and Annual Precipitation at Weather Stations in or Near the Coastal Zone[a].

Station name	Years of record	Mean temperature (°F)	Annual precipitation (in.)
Eastport	1931-1960	43.0	42.7
Woodland	1931-1960	43.1	43.9
Machias	1940-1970	43.1	48.9
Bar Harbor	1941-1970	45.5	48.4
Ellsworth	1942-1972	44.1	43.9
Old Town	1941-1970	41.8	40.7
Bangor	1953-1970	43.9	43.0
Rockland	1940-1970	46.0	46.9
Augusta	1944-1960	45.1	41.0
Lewiston	1941-1970	45.7	43.2
Portland	1941-1970	45.0	40.8

[a] U.S. Department of Commerce NOAA, *irregular*.

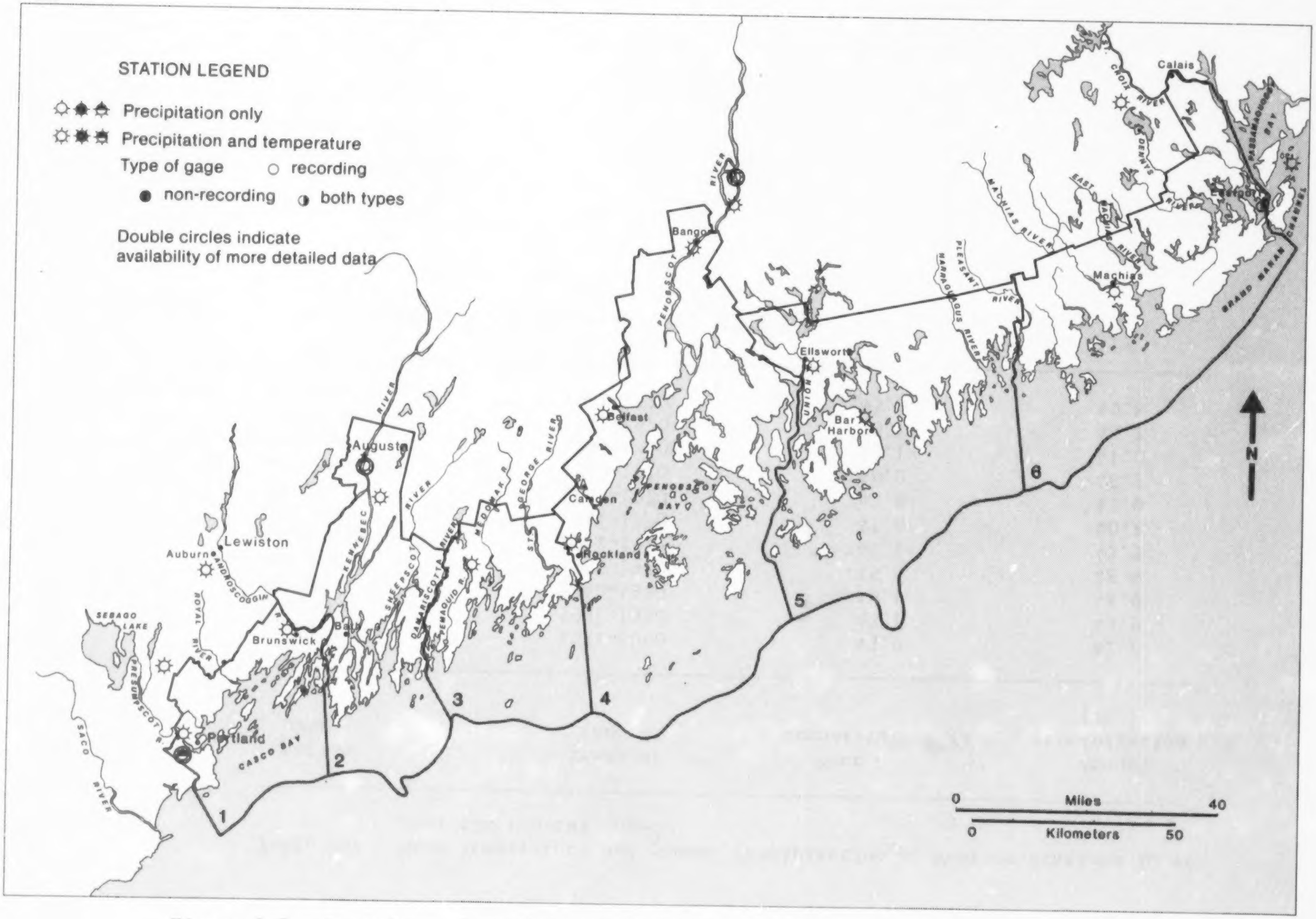

STATION LEGEND
Precipitation only
Precipitation and temperature
Type of gage
○ recording
● non-recording
◑ both types
Double circles indicate availability of more detailed data
Calais
ST. CROIX RIVER
DENNYS
PASSAMAQUODDY BAY
GRAND MANAN CHANNEL
EAST MACHIAS RIVER
MACHIAS RIVER
Machias
PLEASANT RIVER
NARRAGUAGUS RIVER
Ellsworth
UNION
Bar Harbor
RIVER
Bangor
PENOBSCOT
Belfast
Camden
PENOBSCOT BAY
Rockland
ST. GEORGE RIVER
MEDOMAK R.
PEMAQUID R.
DAMARISCOTTA RIVER
SHEEPSCOT RIVER
KENNEBEC
Augusta
Lewiston
Auburn
ANDROSCOGGIN R.
ROYAL RIVER
Brunswick
Bath
SEBAGO LAKE
PRESUMPSCOT R.
Portland
CASCO BAY
SACO RIVER
1
2
3
4
5
6
N
0
Miles
40
0
Kilometers
50

Figure 2-7. Locations of weather stations in and near the coastal zone.

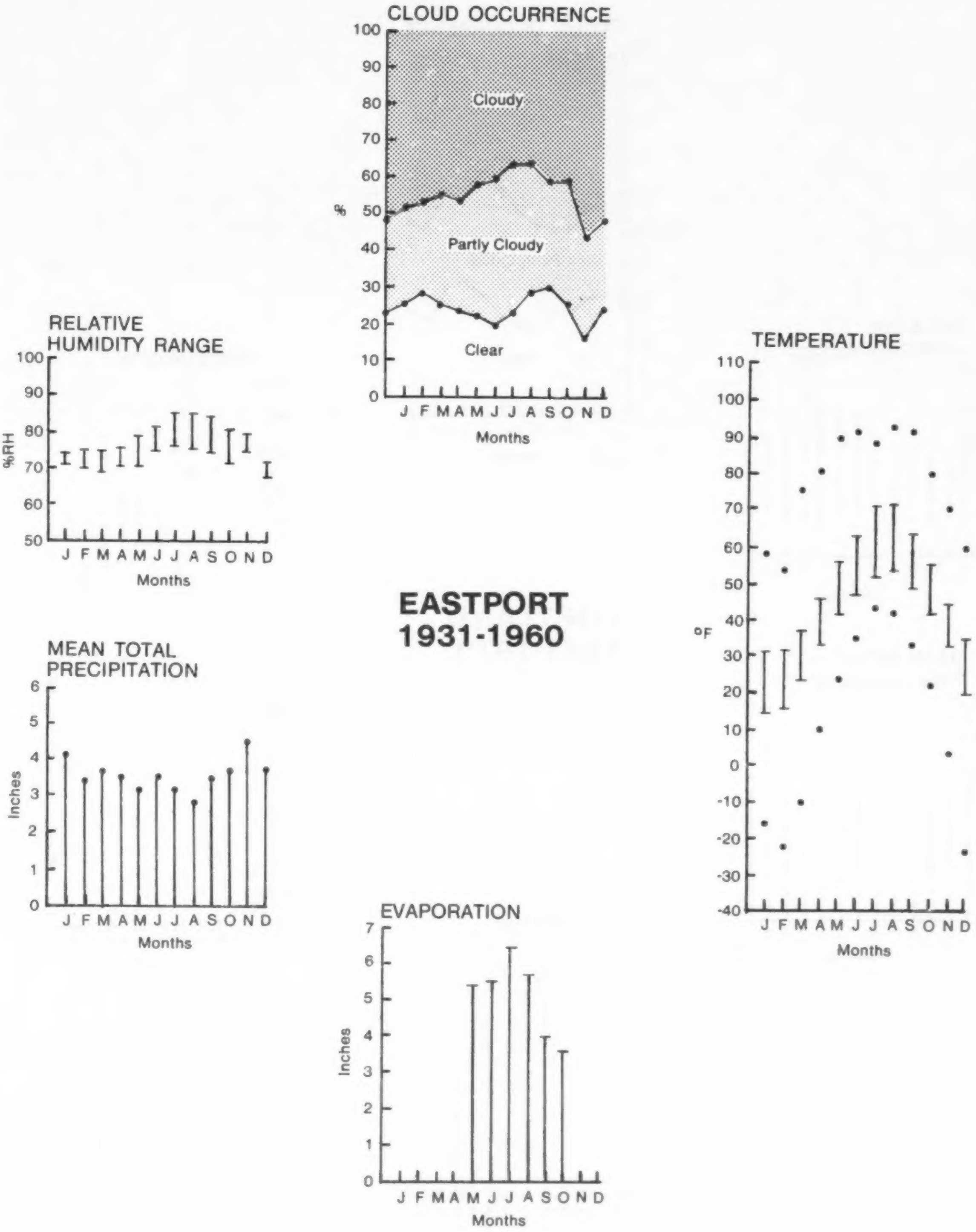


Figure 2-3. Summary of basic climate parameters at Eastport.

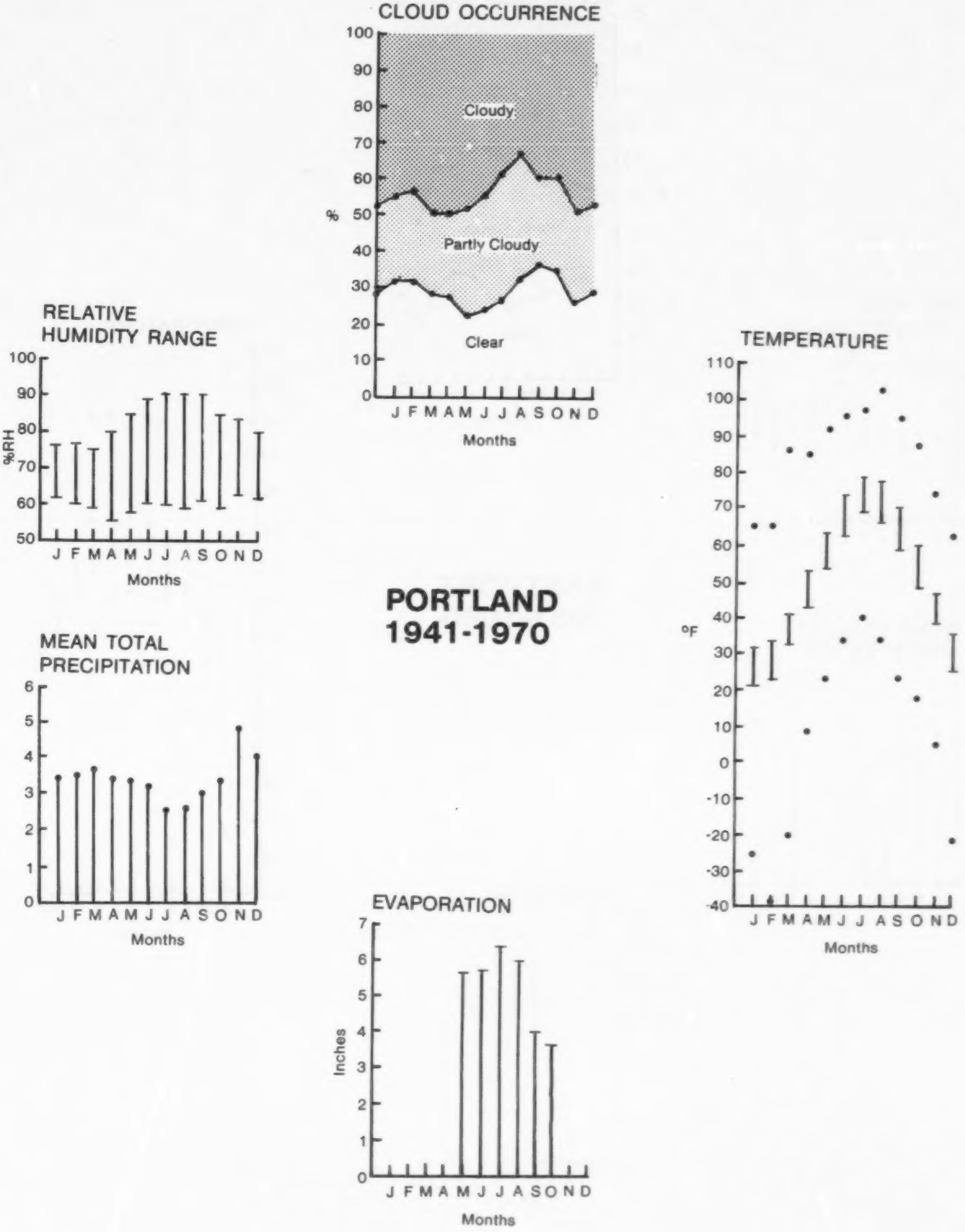


Figure 2-9. Summary of basic climate parameters at Portland.

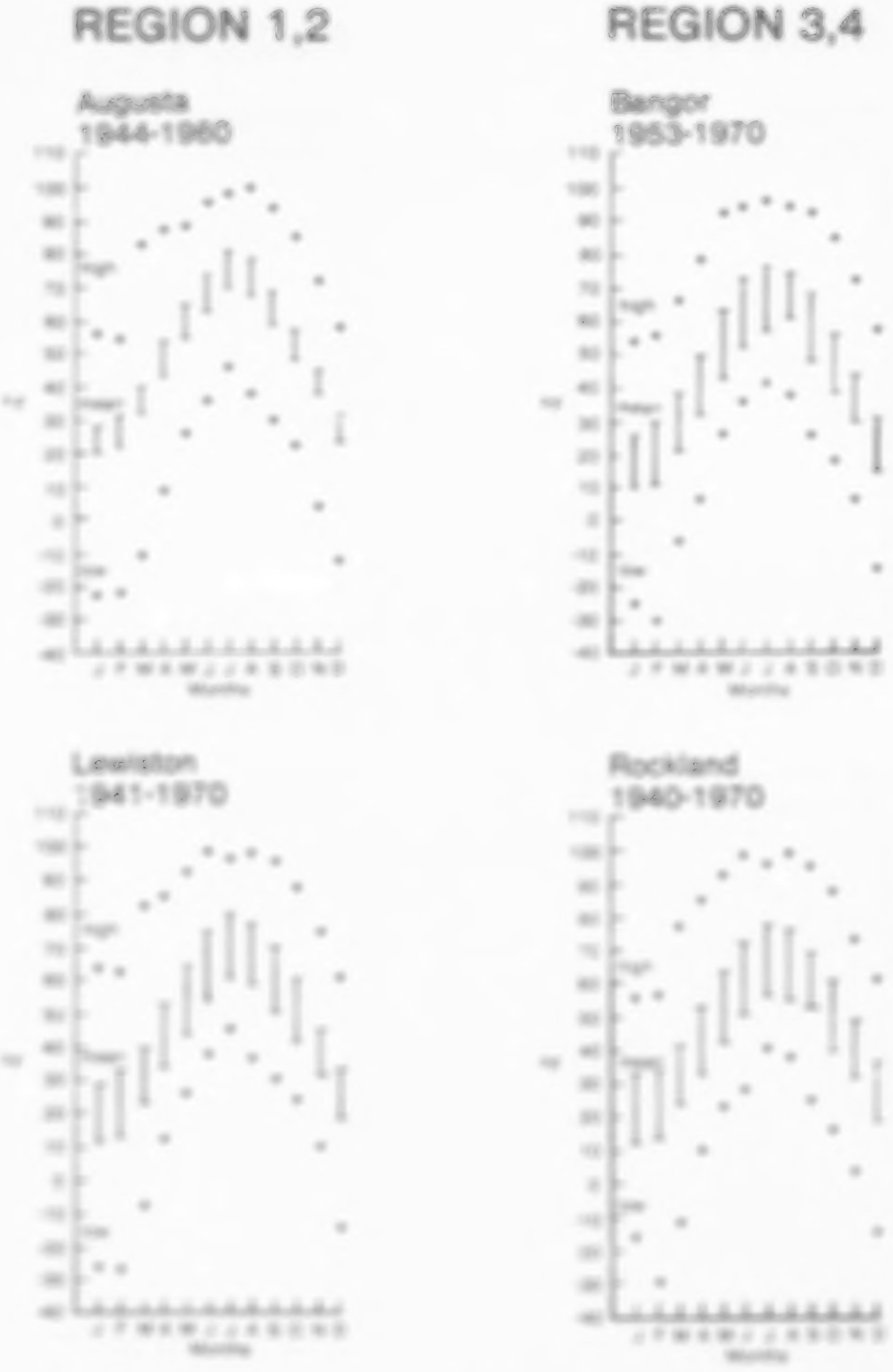


Figure 2-11. Average monthly temperature summaries for eight weather stations in or near the coastal area.

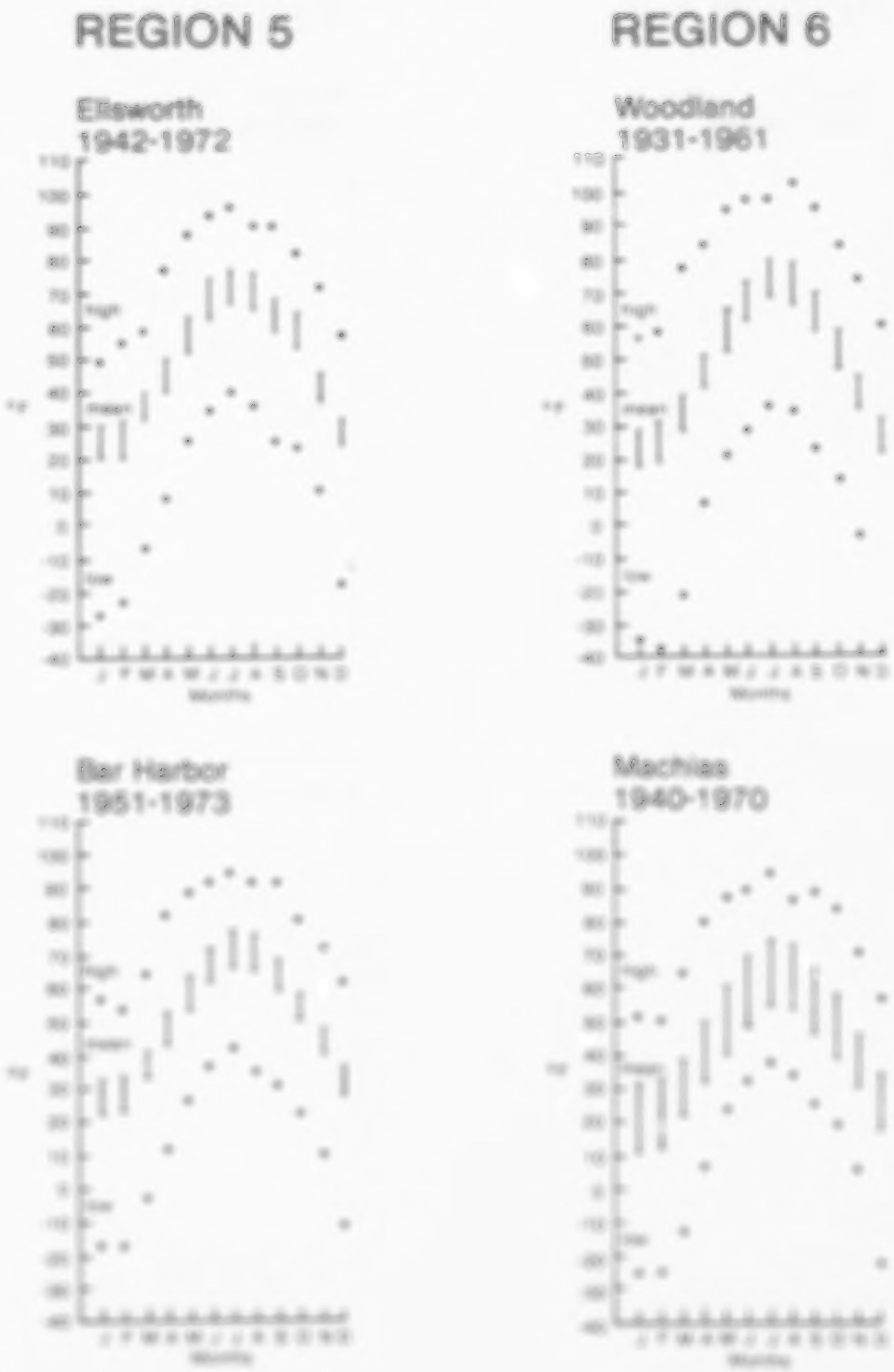


Figure 1-11. (Continued)

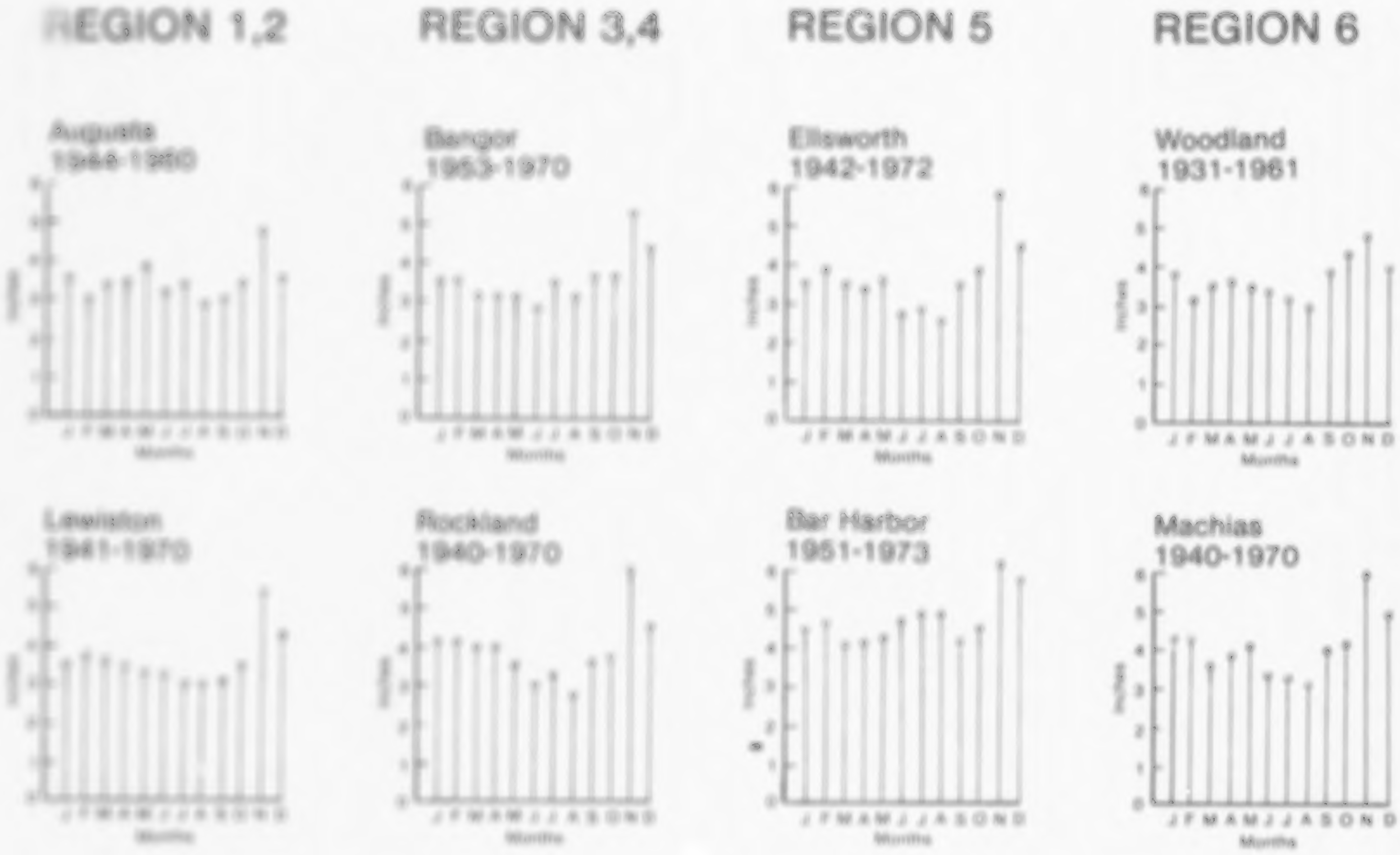


Figure 2-11. Average monthly precipitation summaries for eight weather stations in or near the coastal zone.

Relative humidity data at Portland and Eastport exhibit the greatest variation among all the climate statistics for the two cities. Ranges shown in figures 2-8 and 2-9 represent the average span between afternoon humidities and overnight humidities. The lower bound is determined by the afternoon values, while the upper bound generally is determined by either the midnight or early morning (0700) values. Since the Eastport record contains no midnight observations, peak summer humidities there appear lower than those at Portland. It is expected that these values otherwise would be nearly equal. Significant differences in minimum humidity levels between Portland and Eastport do occur reflecting small differences in distance from the coast. Throughout the year aveage minimum humidity is higher at Eastport than at Portland by 5% to 15% relative humidity.

Surface winds. Seasonal and annual wind patterns at five stations throughout the region have been analyzed through wind roses. Data for four of the recording stations (Portland, Brunswick, Augusta, and Old Town) were obtained directly from the National Climate Center in Asheville, North Carolina. Data for St. John's, New Brunswick, Canada, were obtained from the Canadian Climate Center to represent the eastern coastal region. The latter data differ from those of the other stations in that the wind speed was recorded in miles per hour, rather than in knots. As a result, wind rose categories at St. John are approximate. Qualitative analysis of the wind rose data should not be hampered by this difference.

Wind roses for the four seasons and annual average statistics are given in appendix C for Portland, Brunswick, Augusta, Old Town, and St. John. (Wind records were obtained at a few additional sites but, because of their limited period of record, were not included.) Annual average wind statistics are similar at most stations along the Maine coast. Winds from the west dominate. The true west wind is weakest at Brunswick and Augusta, where local topography affects wind direction. Wind channeling along the major inlets from the sea produces a north-south trend at Brunswick, while a weak northeast-southwest alignment with local hills is seen in the Augusta record. A subtle wind-speed distribution shift is seen also, with the lower wind-speed frequencies decreasing with eastward progression along the coast and the higher wind speed frequencies increasing.

Seasonal statistics provide further insight into the consequences of the observed wind patterns. In winter most winds emanate from the northwest and are associated with the frequent inflows of polar air from the interior land masses of the United States and Canada. These winds are frequently strong and usually are attended by a dry air mass. Winds from the sea account for only 10% of the winter wind in Maine, and these are dominated by the lowest three wind speed classes. High wind speeds come from every sector, however, and these are associated with storm activity. High seas during wind-driven winter storms occasionally cause serious damage to the coast.

In spring, regional variations are more pronounced. Winds at Portland come from the west (including the northwest and southwest) but the south winds increase in frequency due to the onset of sea-breeze conditions. Channeling effects at the other locations are more pronounced, again a result of the increased frequency of south winds. Throughout the coastal region, the south winds and north winds are equally prevalent. By summer, south winds clearly dominate, especially at the stations closest to the shore. These winds, caused by well-developed sea breeze conditions, transport sea fogs and moisture inland. They also deposit salt over land. While sea breezes can only penetrate about 10 miles (16 km) inland, storms can transport salt much farther. Stronger south winds are less frequent.

Fall wind patterns resemble the annual average. Portland and Old Town retain their western compass predominance, while some channeling modification is present at the other locations.

Fog. Fog is prevalent along the coast of Maine and diminishes in frequency of occurrence with distance inland. Thirty-year records at Eastport and Portland show that heavy fog (visibility <0.25 miles;<0.4 km) occurs with a frequency of 60 and 52 days/year respectively (U.S. Department of Commerce, NOAA, irregular). Data on Augusta are availble for only a 3-year period. A 15-day/year average is observed there. When the data are analyzed by season, the extreme eastern and western locations of Eastport and Portland are found to have similar frequencies in all seasons except summer, when Eastport reaches a high of heavy fog on 1 day in 3 and Portland 1 day in 5. The season for lowest fog frequency is winter, when heavy fog averages only 5 to 6 days.

Additional data at the U.S. Coast Guard foghorn stations along the coast between the periods for 1950 to 1969 support the fog frequency observations at Eastport and Portland. These stations are listed in table 2-3 and their locations are shown in figure 2-12. By law, the foghorns are required to operate whenever visibility in adjacent waters is <3 miles (<5 km). These stations regularly log their hours of operation and a summary of their hours of operation is used to compute hourly fog frequencies. The records of foghorn stations in the characterization area are averaged by region in figure 2-13 (stations 1 to 4 are combined under region 6; stations 5, 7, 8, and 9 are combined under region 5; stations 11, 12, and 14 are combined under region 4; station 15 alone represents region 3, stations 16 and 17 are combined under region 2; and 19 to 22 under region 1.) Hourly data on fog frequency along the coast are similar for fall, winter and spring, varying from 10% to 13% (about 1 hour in 10). In summer, however, fog incidence rises sharply, doubling in regions 1 through 4 and almost tripling in region 6. The hourly fog frequency along the coast of region 6 climbs to nearly 1 hour in 3 (33%) in summer.

Inland fog frequency data exhibit much more variation. A high incidence of fog follows the major waterways inland, but as the land mass broadens, fog becomes intermittent. Wetland areas foster local fog generation, as well as lengthen the duration of larger fogs.

Snow. The average annual snowfall along the coast varies from a low of 60 inches (152 cm) at Rockland to a high of 97 inches (246 cm) at Bangor (U.S. Department of Commerce, NOAA, irregular). The low annual snowfall near the coast (Rockland) in comparison with that at the inland boundary of the coastal zone (Bangor) is the most graphic example of a trend that is apparent throughout the coast.

Data on average snowfall are summarized in figure 2-14. The three stations closest to the coast are those with the three lowest snowfall amounts: Eastport, Bar Harbor, and Rockland. Differences among the remaining stations appear to be the result of local characteristics and distance inland.

Table 2-3. U.S. Coast Guard Foghorn Stations along the Maine Coast.

Number	Name	Latitude (N°)	Longitude (W°)
1	W. Quoddy Head	44.82	66.95
2	Little River	44.65	67.19
3	Libby Island	44.57	67.37
4	Moose Point	44.48	67.53
5	Petit Manan	44.37	67.87
6	Mt. Desert	43.97	68.13
7	Egg Rock	44.35	68.14
8	Bass Harbor	44.22	68.34
9	Burnt Coat Harbor	44.14	68.45
10	Matinicus Rock	43.78	68.86
11	Owls Head	44.09	69.05
12	Fort Point	44.47	68.81
13	Manana Island	43.76	69.33
14	Whitehead	43.98	69.13
15	Marshall Point	43.92	69.26
16	The Cuckolds	43.78	69.65
17	Seguin	43.71	69.76
18	Doubling Point	43.88	69.81
19	Halfway Rock	43.66	70.04
20	Portland Light Ship	43.53	70.09
21	Cape Elizabeth	43.57	70.20
22	Portland Head	43.62	70.21
23	Wood Island	43.46	70.33
24	Goat Island	43.36	70.43

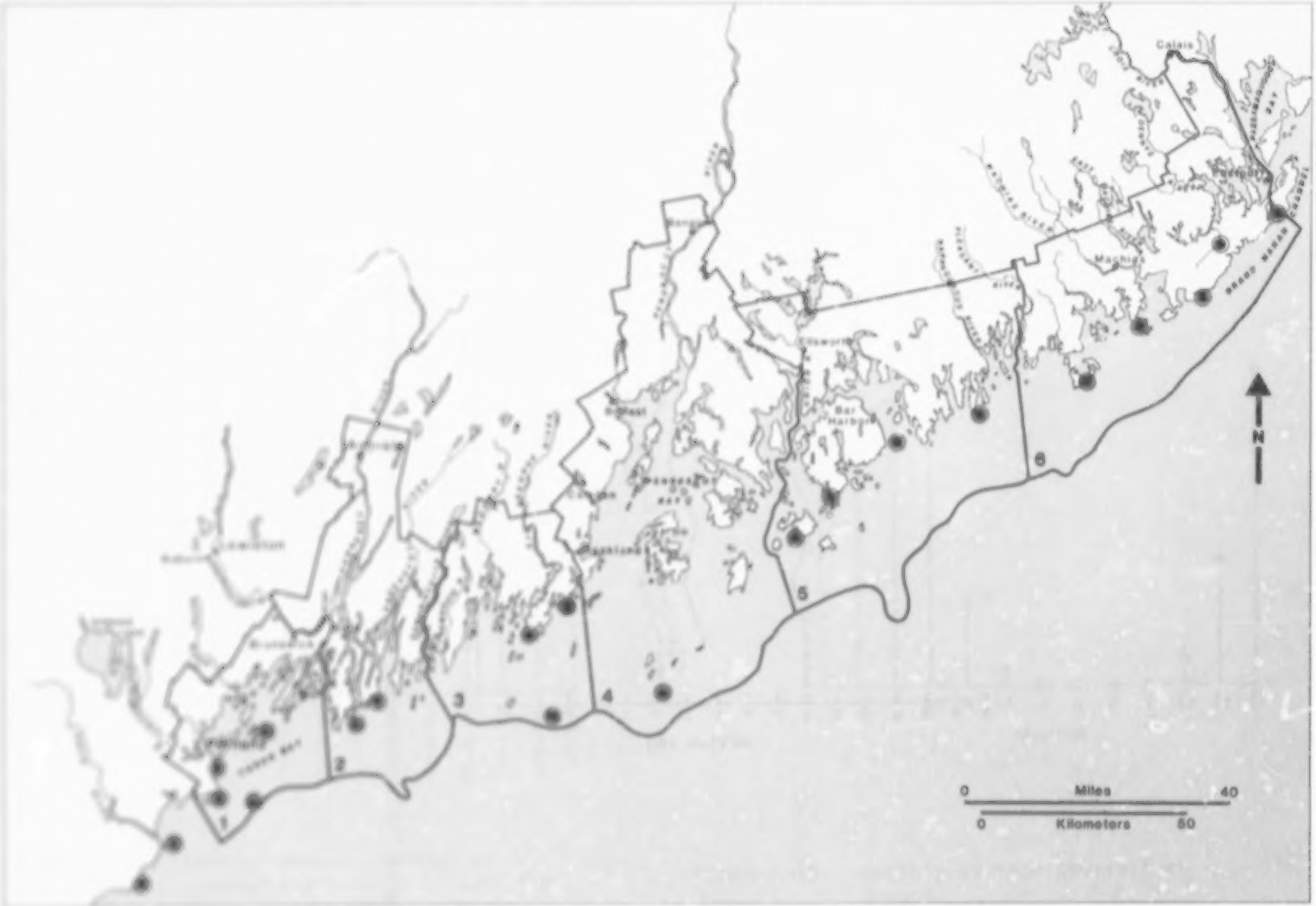

Calais
Eastport
Machias
Bar Harbor
Ellsworth
Bangor
Penobscot Bay
Rockland
Portland
Casco Bay
Brunswick
Lewiston
Grand Manan Channel
Passamaquoddy Bay
1
2
3
4
5
6
N
0
Miles
40
0
Kilometers
50

Figure 2-12. Locations of foghorn stations in the characterization area.

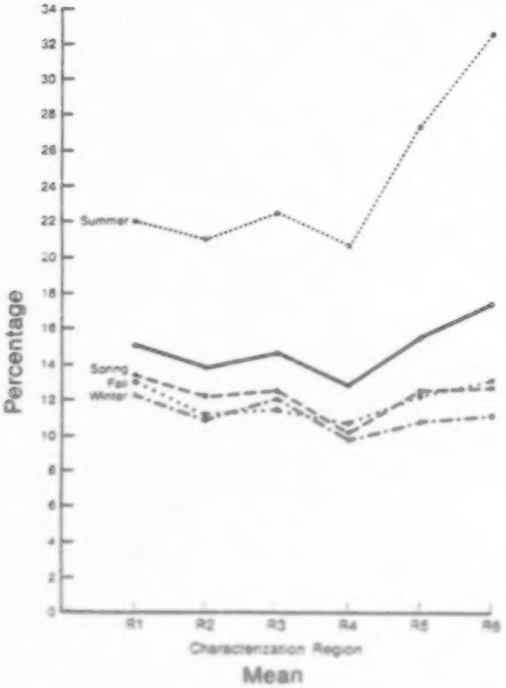


Figure 2-13. Seasonal fog occurrence along the Maine coast, by region.

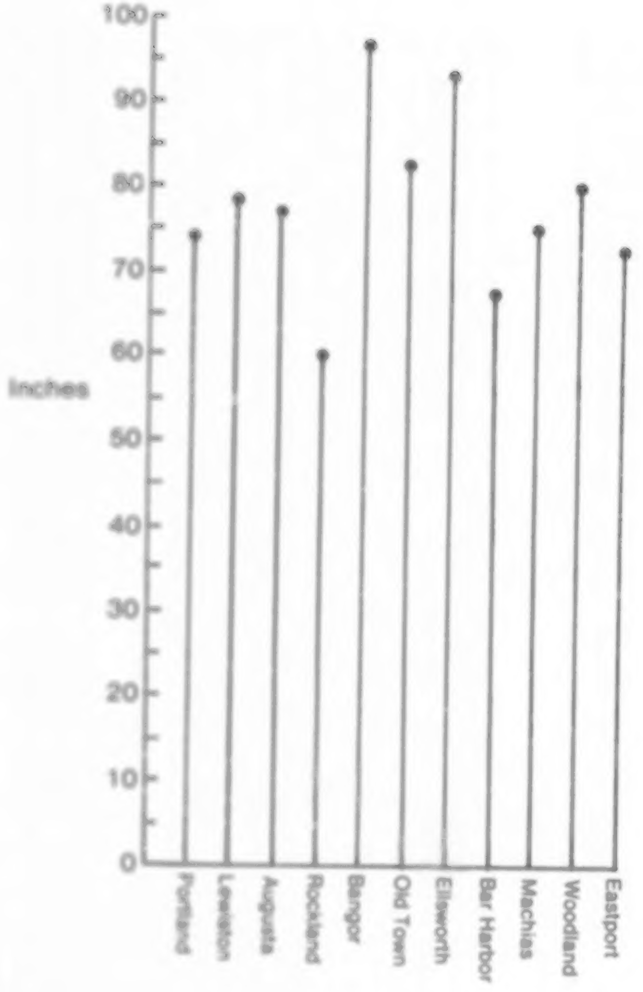


Figure 2-14. Average annual snowfall at 16 weather stations in or near the coastal zone.

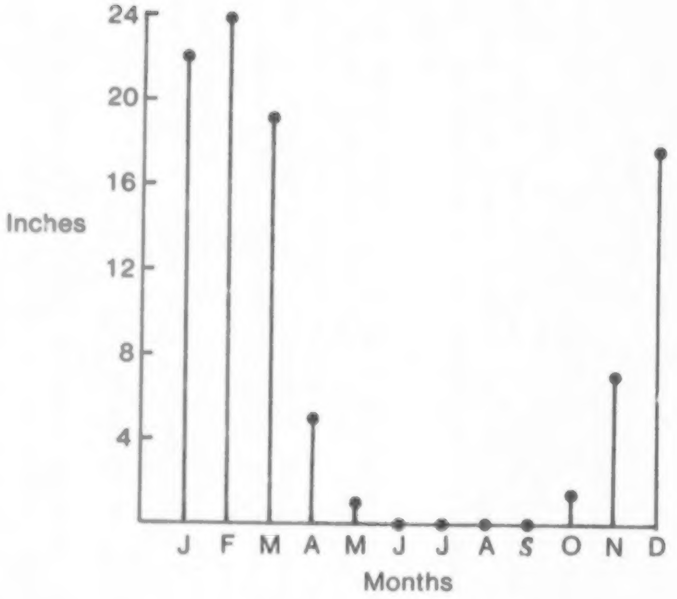


Figure 2-15. Monthly average snowfall at Bangor.

Snowfall statistics at 11 weather stations in the characterization area are summarized in table 2-4. Variability in snowfall depths from year to year can be substantial at all stations. Minimum amounts vary from 24 inches (61 cm) at Ellsworth to 46 inches (117 cm) at Lewiston, while maximum amounts range from 106 inches (269 cm) at Augusta to 182 inches (462 cm) at Bangor. These statistics generally apply to a period of 30 years. In an average year, the number of days with snowfall >1 inch (2.5 cm) varies from 18 to 23, while that for snowfall >4 inches (10 cm) varies from 5 to 8 days throughout the coastal zone. Average snowfall >10 inches (25.4 cm) does not exceed 1 day/year at any station.

Average monthly snowfall is highest in February at nearly all stations. The greatest amount of snow falls between December and March. The snowfall distribution at Bangor, shown in figure 2-15, is typical of the entire area, although a greater amount of snow falls at Bangor. A comparison of snowfall and total precipitation data for November and December indicates that most of the precipitation during these months is rain. Consequently, natural water storage areas are replenished at the start of most winters. The ensuing cold temperatures will cause much of this water to be held as ice until the first major thaws. This, combined with the melting of accumulated snowfall, results in spring flooding of wetlands.

The period of maximum snowfall is also the period of maximum snow depth and maximum continuous snow cover in coastal Maine. Maximum snow cover duration averages about 50 days on the immediate coast and up to 70 or 80 days at the inland boundary of the coastal zone. Yearly variability in snow cover is high, with the shortest maximum duration averaging 7 days on the coast and 14 days inland. The longest average maximum snow cover duration ranges between 11 and 132 days. Average maximum snow depths range from 14 to 25 inches (36 to 64 cm). Although a significant amount of snow cover is present during most winters, an abnormally clear season occurs approximately every 6 to 8 years. Snow cover duration and depth at nine locations in the characterization area are summarized in table 2-5.

Freeze penetration and the growing season. The length of the growing season commonly is determined by the length of the average freeze-free period. Some vegetation is damaged by temperatures 32°F (0°C). The mean duration of the freeze-free period at 11 weather stations in coastal Maine is given in table 2-6. The range is 131 to 174 days.

The four stations with the longest period of record are Eastport, Woodland, Bar Harbor, and Lewiston. Woodland, near the inland boundary of the coastal zone and the most northerly station, exhibits the shortest growing season and Eastport the longest. Bar Harbor and Lewiston are in the middle of this range but are closer to the Eastport value. These figures indicate that while distances from the coast can be an important factor in the growing season, other local effects may be equally important.

A measure of the severity of the winter season is the freezing index. This index is based on the computation of degree-days. Degree-days are a measure of the number of degrees below 32°F (0°C) of the average (of maximum and minimum) temperature for a given day. For example, an average daily temperature of 15°F (-9°C) yields a value of 17 degree-days. The air-freezing index for a given freezing season is the number of degree-days between the

Table 2-4. Snowfall Statistics for Stations in or Near Coastal Maine[a]

Station	Record	Annual snowfall (in.)			Number of days with snow greater than:					
		Ave.	Min.	Max.	1"	2"	4"	6"	8"	10"
Eastport	1931-1960	67	29	132	19	12	5	2	1	0.3
Woodland	1931-1960	80	40	119	23	15	7	3	2	0.5
Machias	1940-1970	75	27	132	21	14	7	3	1	0.5
Bar Harbor	1951-1973	68	--	--	--	--	--	--	--	--
Ellsworth	1942-1972	94	34	115	23	15	6	2	1.3	1
Old Town	1951-1971	82	--	--	--	--	--	--	--	--
Bangor	1953-1970	97	33	182	23	15	7	4	2	1
Rockland	1940-1970	60	30	113	20	11	5	2	1	0.5
Augusta	1944-1960	77	29	106	23	15	8	--	--	1
Lewiston	1941-1970	78	46	145	21	13	6	3	2	1
Portland	1940-1976	74	31	142	18	--	6	--	1	--

[a]U.S. Department of Commerce, irregular.

Table 2-5. Snow Cover Depths and Duration for Stations in or Near Coastal Maine[a]

Station	Record	Maximum continuous duration (days)			Average max. depth (in.)
		Ave.	Min.	Max.	
Eastport	1931-196	50	7	112	14
Woodland	1931-196	--	--	111	20
Machias	1940-197	61	7	119	20
Ellsworth	1942-197	71	14	132	22
Bangor	1953-197	71	14	120	25
Rockland	1940-197	52	8	107	19
Augusta	1944-196	85	16	124	24
Lewiston	1941-197	70	14	120	24
Portland	1940-197	50	--	---	--

[a]U.S. Department of Commerce, irregular.

Table 2-6. Average Length of the Growing Season at 11 Weather Stations in or Near the Coastal Zone[a].

Station name	Period of record	Freeze-free period (days)
Eastport	1931-1968	174
Woodland	1931-1968	131
Machias	1954-1968	132
Bar Harbor	1931-1968	156
Bangor	1953-1968	156
Old Town	1948-1968	118
Rockland	1937-1968	143
Augusta	1945-1968	159
Brunswick	1952-1968	163
Lewiston	1931-1968	168
Portland	1941-1968	136

[a] U.S. Department of Commerce 1973b.

Table 2-7. Air-freezing Index (32 ° F degree-days) at 11 Weather Stations in or Near the Coastal Zone[a].

Station name	Years of record[b]	Air-freezing index[c]		
		1 in 10	1 in 30	Mean
Eastport	30	1150	1249	810
Woodland	25	1627	1809	--
Machias	--	1363	--	--
Bar Harbor	27	1071	1073	680
Bangor	23	1519	1865	1225
Old Town	--	1874	--	--
Rockland	27	1103	1173	740
Augusta	--	1458	--	--
Brunswick	--	1323	--	--
Lewiston	30	1386	1446	990
Portland	30	1227	1376	910

[a] Bigelow 1969.

[b] Nominal 30-year record runs from 1938 to 1968, while all 10-year records run from 1958 to 1968.

[c] 1 in 10 is the index value for the coldest season in 10 years and 1 in 30 is the index value for the coldest season in 30 years.

highest and lowest points on the curve of cumulative degree-days. The longer the season and the colder the temperature, the greater is the freezing index. The mean air-freezing index, the highest in 10 years, and the highest in 30 years at weather stations in the coastal zone, are given in table 2-7. These data clearly show the moderating effect of coastal waters on winter air temperatures. The stations nearest the coast register indices between 1071 and 1227 degree-days, while those farthest inland record indices between 1519 and 1874 degree-days.

The ecological consequences of low temperatures during severe winters are related primarily to the depth to which the ground freezes. This depth can be estimated from the air-freezing indices and soil composition. Frost depths are defined as the seasonal maximum penetration of the 32°F (0°C) isotherm. Estimations of frost depths using air freezing indices involve heat transfer theory and cannot account for local variability. An area's exposure to sunlight and wind can have a marked modifying influence.

Sanger (1963) used frost-penetration curves and air-freezing indices to estimate frost depths. He considers seven soil-composition grades and three surface conditions. The results of applying the characterization area indices to his curves are summarized in tables 2-8 through 2-10. Depths associated with turf are the upper bound for most of the areas involved , with the 12-inch snow cover as a lower bound. Areas nearest the coast frequently are not covered with 12 inches of snow, however, so the turf values only should be considered in those areas.

In an average year, with a coastal air freezing index of approximately 800 degree-days and an inland index of approximately 1300 degree-days, frost penetration in similar soils is about equal if the "turf" category is used for the coast and the "turf + 12 inches snow" category is used inland. Similarly, the same result is obtained when the coldest season in 10 indices are used (1300 degree-days near the coast, 1800 degree-days inland). Consequently, average frost penetration in the inland regions may be less severe than might be expected, since snow depths are greater and last longer there than in the warmer coastal regions.

River and harbor ice. The formation of ice on the rivers and bays of Maine's coastal region is a prominent though poorly documented characteristic of the winter season. Many factors contribute to ice formation. Not only does the salt content of estuarine water reduce freezing temperature, but mechanical agitation from winds, currents, and tides also prevents the formation of ice cover at temperatures below 32°F (0°C). As a result, the more isolated, brackish, and inland waters are most susceptible to ice cover, and the salt water bays and inlets are least susceptible.

The annual reports of the U. S. Coast Guard on ice-breaking activities are the most comprehensive summary of river and harbor ice occurrence in coastal Maine (U. S. Coast Guard 1970 to 1978). Their activity reports on the Penobscot River document significant ice formation from an inland river environment to a coastal bay environment, and ice conditions in the Penobscot region are likely to be indicative of ice conditions elsewhere in the coastal zone.

A second source of data on ice occurrence on the eastern coast is the personal records of Mr. Richard [illegible] of North Lubec, Maine (personal

Table 2-8. Maximum Seasonal Depth of Frost for an Air-freezing Index of 850 degree-days°F

Soil type	Frost penetration (in.)		
	Bare ground	Turf	Turf + 12 in.
Clay and damp top soil	21	13	9
Silt and sandy silt	30	20	14
Silty sand	36	24	16
Sand and silty sandy gravel	40	26	18
Gravel and sand	46	29	21
Glacial till	50	33	24
Well-drained, sandy gravel	56	37	26

Table 2-9. Maximum Seasonal Depth of Frost for an Air-freezing Index of 1300 degree-days°F

Soil type	Frost penetration (in.)		
	Bare ground	Turf	Turf + 12 in.
Clay and damp top soil	30	20	14
Silt and sandy silt	41	29	22
Silty sand	48	35	26
Sand and silty sandy gravel	52	38	28
Gravel and sand	59	44	32
Glacial till	64	48	36
Well-drained, sandy gravel	78	54	39

Table 2-10. Maximum Seasonal Depth of Frost for an Air-freezing Index of 1800 degree-days°F

Soil type	Frost penetration (in.)		
	Bare ground	Turf	Turf + 12 in. snow
Clay and damp top soil	38	27	20
Silt and sandy silt	50	38	29
Silty sand	58	44	34
Sand and silty sandy gravel	65	48	38
Gravel and sand	73	56	43
Glacial till	78	60	48
Well-drained, sandy gravel	99	71	53

communication; September, 1979), which span a 19-year period (1959 to 1978) in the Eastport area. Mr. Rhine's observations, in combination with the Coast Guard records, provide the only available record of ice occurrence along the Maine coast.

Coast Guard records for the six winters prior to and including 1978 indicate that sufficient ice forms on the Penobscot River to require breaking by the first week of December. The latest breaking in the season occurred on 20 December 1973, whereas the earliest occurred on 3 December 1972. River and harbor ice usually is a navigation problem through early March, varying from 12 February in 1976 to 17 March in 1974 and 1975. The last ice-breaking operation of the year is usually in the Kennebec River, where flood control requires the use of ice breakers in removing floating-ice buildup during the main thaw. The average breaking period is 91 days.

Midwinter maximum ice thickness of the Penobscot River has varied from 6 inches (15 cm), broken and moving, to 12 inches (30 cm). Ice thickness at pressure ridges and areas of rafting can vary from 24 to 36 inches (61 to 91 cm). Protected waters of the river have average maximum thicknesses in excess of 20 inches (51 cm). The ice jams in spring on the Kennebec reached a maximum thickness of 15 feet (4.6 m) in 1978. Average ice thickness during mild years is 1 to 4 inches (3 to 10 cm) on the Penobscot. In more severe years the average has been 2 to 6 inches (5 to 15 cm). The upper Penobscot is always more prone to freezing over than is the lower Penobscot.

Reported ice conditions for the eastern coast include the harbors and passages between Eastport and Campobello Island. Ice in this area is made up of either shore ice, floating ice chunks, or solid ice, and usually occurs in the smaller bays and inlets. Of these three shore ice is the most frequent. During high winds, shore ice tends to pile up on adjoining beaches.

From 1959 to 1978, shore ice was observed an average of 11 days/season. Approximately 1 year in 5 was colder than average, with over 20 days of observed shore ice, whereas 2 years in 5 were mild, with 4 days or less of observed shore ice. Of the mild years, half had no significant amounts of shore ice.

Freezing of harbors and small inlets is less frequent than the formation of shore ice. More than half of the seasons show no ice cover, while roughly two seasons in five record freeze periods in excess of 7 days. Half of these have freeze periods lasting 2 to 3 weeks. The thickness of solid ice generally remains less than 12 inches (30 cm), with isolated areas reaching up to 24 inches (61 cm).

Little ice formation has been observed along the eastern coast in either December or March. Ice formation begins in early January and may continue through mid-February. This is in contrast to rivers and bays farther inland, such as those along the Penobscot River, where significant ice formation begins in early December and continues through early to mid-March.

Storm occurrences. Heavy ice storms ("glaze" or freezing rain) affect people most directly through power losses (due to icing of power lines) or dangerous driving conditions. They also may topple trees and thereby damage buildings. Broken trees and shrubs in the wake of severe storms are the most visible evidence of the impact of ice storms on the natural environment. The institutions that have been most interested in collecting and analyzing ice storm data are the transportation, power, and communications industries. The most common measure of icing is the thickness of ice on power lines.

According to Bennett (1959) the thickness of ice deposits can vary considerably over a small region, because of the inherent nature of the storms as well as local meteorological conditions. The heaviest deposits occur in areas having low temperatures and strong winds. Although concurrent wind data are scarce, Bennett points out that moderate velocities (around 10 to 20 mph; 16 to 32 km/hr) are most common during ice storms. The Edison Electric Institute (Bennett 1959) recorded data on ice storms across the nation from 1926 to 1927 and from 1936 to 1937 that show the thickness of ice deposits is associated with high wind speeds. According to Edison Electric data from Massachusetts, glaze on utility wires has a maximum duration of 55 hours, a minimum duration of 3 hours, and an average duration of 20 hours. Similar durations may be expected at the interior boundary of the Maine coastal zone, with somewhat shorter durations on the immediate coast.

Bennett (1959) quotes two additional studies of ice storms: one by the Association of American Railroads (1928 to 1937) and another by the American Telephone and Telegraph Company (AT&T; 1917 to 1925). The first records a total of approximately 22 storms in the southern third of the Maine coast, 13 in the central third, and 7 in the northern third over the 9-year observation period. Approximately half of these storms deposited an ice layer $\geq$0.25

inches (0.6 cm) on power lines. Storms producing 0.5-inch (1.3 cm) ice layers were observed on about six occasions on the southwest coast and three to five occasions on the northeast coast. The greatest thicknesses observed in these storms were 1.75 to 1.99 inches (4 to 5 cm) on the coast and 0.75 to 0.99 inches (2 to 3 cm) in inland regions. Similarly, the AT&T data show about 6 damaging storms, one every 3 years along the coast and every 6 years inland.

Data gathered by the U.S. Weather Bureau show that light freezing rain occurs much more frequently than damaging ice storms. The mean annual number of days with freezing rain ranges from 8 to 12 (U.S. Department of Commerce 1973a). AT&T's 8-year study indicates that heavy ice storms may be expected on an average of 1 day/year. As stated above, damaging ice storms may be expected approximately every 3 years along the coast and every 6 years inland. Therefore, areas that are stressed by heavy ice accumulations can expect several "good" years between storms, whereas areas affected by thin ice glazing must bear some losses every year, with greater damage occurring every few years.

Due to the cooler air prevalent along the coast during summer, thunderstorms are less frequent throughout the coastal zone than in central Maine. Average frequencies along the coast vary from 14 thunderstorm days/year at Eastport to 18 thunderstorm days/year at Portland [U.S. Department of Commerce, (NOAA) irregular]. Total numbers of thunderstorms for individual years may range from 6 to 30. Stations along the inland boundary of the coastal zone show frequencies similar to those of the nearby shoreline stations. Woodland, Bangor, Augusta, and Lewiston average 14, 17, 18, and 17 days/year respectively. Available thunderstorm frequency data are summarized in table 2-11.

The period of greatest thunderstorm frequency covers the summer season, from June through August. Since summer is also driest, fires caused by lightning pose a serious threat. Associated hail damage is infrequent.

The historical record shows few effects of tropical storms on the characterization area. Portland has not recorded any. Farther up the coast, however, the probability of a tropical storm or hurricane in any 1 year is 7% (Lautzenheiser 1972). Absolutely no "great hurricanes" have been recorded for the coast of Maine. Tropical storms lose much of their intensity before reaching coastal Maine and so are reduced to heavy rain and moderate winds, such as those in a "northeaster."

Geology

The geological component of an ecosystem is the substrate on and in which the flora and fauna exist. The subtrate consists of exposed solid bedrock or unconsolidated deposits underlain by bedrock.

To understand the function of geological processes in an ecosystem, it is necessary to have a knowledge of the origin, composition, and surface distribution of the different bedrock types, the nature and origin of the unconsolidated deposits, and the processes and mediums that change bedrock to unconsolidated sediments and that have transported them to their present environments.

Table 2-11. Average Occurence of Thunderstorms at Nine Weather Stations in or Near the coastal Zone.

Station name	Period of record	Average number of storms/year
Eastport	1931-1960	14
Woodland	1931-1960	14
Machias	1940-1970	15
Ellsworth	1942-1972	16
Bangor	1953-1970	17
Rockland	1940-1970	13
Augusta	1944-1970	18
Lewiston	1941-1970	17
Portland	1940-1976	18

[a] U.S. Department of Commerce, irregular.

The geological elements that influence the activity, distribution, and abundance of plant and animal populations include bedrock formation and surficial and marine geological processes. Geological factors dictate the chemical and physical properties of surface soil, which affects the vegetative composition and the distribution of populations in the area and presents opportunities and limitations to human culture. The response of geological elements to both natural and artificial forces, such as dredging, sea wall construction, dam construction, and filling, may be the initiation of sedimentation and erosion, which changes the physical substrate and affects the water column. Bedrock geology, glacial geology, sea level changes, erosion, sedimentation, surficial geology, and hydrology are discussed below as they apply to the Maine coast. Information on the geological characteristics of each of the systems, including the formation and composition of the systems and classes can be found in the appropriate systems chapters (4 through 10). A specific discussion on the availability of geological information for each region can be found in appendix D. Marine geology and unique geological features of coastal Maine are detailed on atlas map 3.

General physiography: bedrock control of the coastal platform. The geology of the Maine coast, characterized by deeply indented embayments, straight, high, rocky cliffs, broad mud flats, and numerous coastal islands, is unique in the Eastern United States. Maine's complex shoreline physiography is determined by the structured nature of the bedrock. The bedrock determines the general shape of the shoreline and the shallow complex bathymetry of the coastal waters. The Maine coast from Cape Elizabeth to Eastport can be seen as three segments on the basis of bedrock geology (figure 2-16). Regions 1, 2, and 3 are included in the area characterized by indented embayments. Regions 4, 5, and part of region 6 (east to Machias Bay) are included in the island bay complex. The eastern area of region 6 is characterized by a cliff shoreline.

Bedrock units are cut transversely by fault and fracture systems of varying orientations and ages. The major fracture system that cuts coastal bedrock units (generally from southwest to northeast) developed during the late Devonian-Triassic time frame (180 to 350 million years ago). Fracture systems in the bedrock exert major control over groundwater flow. A record of geological events and their correlation with plant and animal evolution is given in figure 2-17.

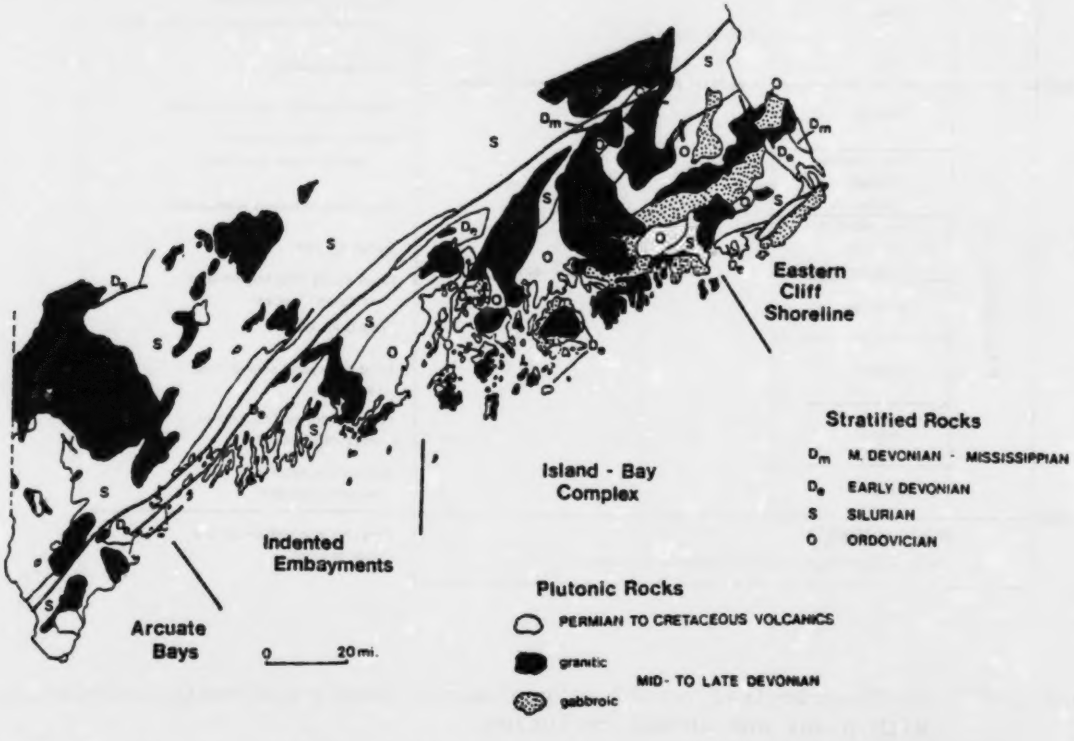
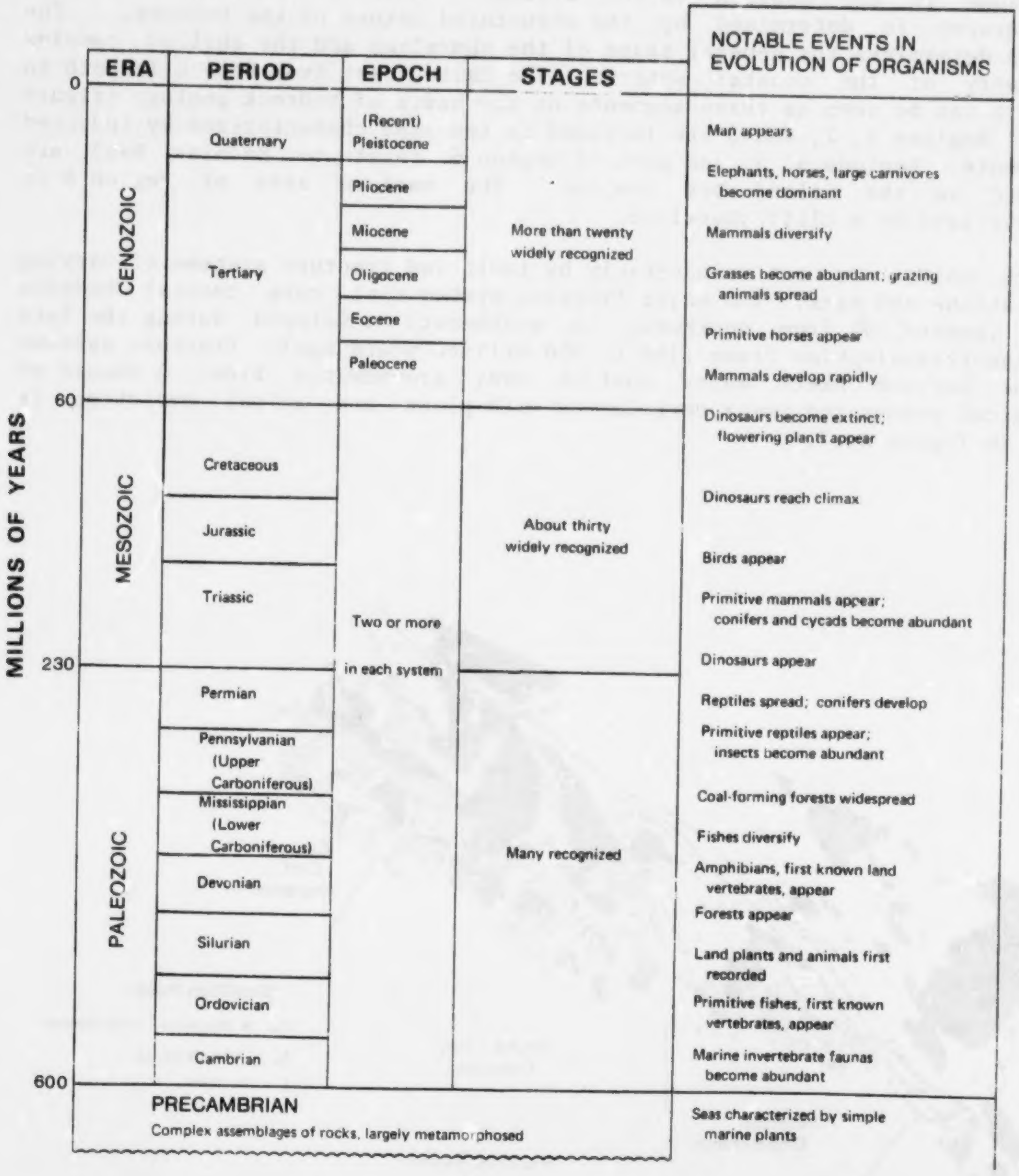

Eastern Cliff Shoreline
Island - Bay Complex
Indented Embayments
Arcuate Bays
0 20 mi.
Stratified Rocks
D_m M. DEVONIAN - MISSISSIPPIAN
D_e EARLY DEVONIAN
S SILURIAN
O ORDOVICIAN
Plutonic Rocks
PERMIAN TO CRETACEOUS VOLCANICS
granitic
gabbroic
MID- TO LATE DEVONIAN

Figure 2-16. Bedrock geology of coastal Maine (Doyle 1967).



MILLIONS OF YEARS	ERA	PERIOD	EPOCH	STAGES	NOTABLE EVENTS IN EVOLUTION OF ORGANISMS
0	CENOZOIC	Quaternary	(Recent) Pleistocene	More than twenty widely recognized	Man appears
		Tertiary	Pliocene		Elephants, horses, large carnivores become dominant
			Miocene		Mammals diversify
			Oligocene		Grasses become abundant; grazing animals spread
			Eocene		Primitive horses appear
			Paleocene		Mammals develop rapidly
60	MESOZOIC	Cretaceous	Two or more in each system	About thirty widely recognized	Dinosaurs become extinct; flowering plants appear
		Jurassic			Dinosaurs reach climax Birds appear
		Triassic			Primitive mammals appear; conifers and cycads become abundant Dinosaurs appear
230	PALEOZOIC	Permian		Many recognized	Reptiles spread; conifers develop
		Pennsylvanian (Upper Carboniferous)			Primitive reptiles appear; insects become abundant
		Mississippian (Lower Carboniferous)			Coal-forming forests widespread Fishes diversify
		Devonian			Amphibians, first known land vertebrates, appear Forests appear
		Silurian			Land plants and animals first recorded
		Ordovician			Primitive fishes, first known vertebrates, appear
		Cambrian			Marine invertebrate faunas become abundant
600	PRECAMBRIAN Complex assemblages of rocks, largely metamorphosed				Seas characterized by simple marine plants

Figure 2-17. A chronological record of geological events and their correlation with plant and animal evolution.

Covering the bedrock platform are unconsolidated deposits associated with the Pleistocene period of glaciation, which began approximately 1 million years ago and ended in coastal Maine from 12,000 to 13,000 years ago (Stuiver and Borns 1975). Reworking of the glacially derived deposits by upland and marine forces has created shoreline, intertidal, and shallow subtidal sedimentary deposits that presently fill the low areas between the bedrock platform highs along the coast (atlas map 3).

Pleistocene glaciation, deglaciation, and associated deposits. The glacial deposits constituting the surface soils of the upland were laid down by glacial ice or glacial meltwater processes during the last phase of Pleistocene glaciation (i.e., the Wisconsin Age). Approximately 28,000 years ago, a glacial mass covered all of Maine and extended out to the edge of the present continental shelf at Georges Bank (Schlee and Pratt 1970). At the bedrock-glacial ice interface two types of activity occurred: (1) thin (2 to 10 m thick; 6.5 to 33 feet) deposits of glacial till were laid down; (2) the bedrock surface was scoured of all loose, unconsolidated cover.

Approximately 13,200 years ago, the glacier margin receded from its terminal position on the Atlantic continental shelf to about the present position of the coast of Maine (Stuiver and Borns 1975). The subsequent retreat of the ice margin approximately 12,800 years ago to a position about 44 miles (70 km) inland of the present shoreline left the coastal area exposed to subaerial and marine erosion processes.

Because the earth's crust was depressed by the weight of the glacial mass, the land surface (immediately after glacial recession) was about 400 feet (120 m) below present elevations. This crustal depression allowed much of the land surface to be inundated by marine waters from the Gulf of Maine. Along the coast, the limit of marine incursion stands presently at elevations of 240 to 290 feet (973 to 88 m; Goldthwait 1949).

At higher elevations, meltwater from the receding glacier margin deposited stratified sands and gravels into glacial landforms, such as kames, kame terraces, moraines, eskers, outwash plains, and large deltaic complexes at the shoreline (atlas map 3). Boulders, gravel, and sand on the surface of the glacier were left as a blanket of coarse-textured till and in a few coastal localities were reworked by proglacial climate wind into thin eolian deposits.

Clays and silts were transported to the ocean, where they settled to form extensive blanket deposits of glaciomarine clay. This clay, ubiquitous at lower elevations along the Maine coast, is called the Presumpscot Formation (Bloom 1963). Late Pleistocene shoreline environments (beaches and spits) are preserved on the upland. These separate till and stratified drift from the marine clay found at lower elevations.

After the glacial margin receded, crustal uplift took place. By 12,000 years ago, most of the submerged coastal lands were exposed to subaerial weathering. Continued rebound of the land mass lowered sea level approximately 8500 years ago to approximately 197 feet (60 m) below the present shoreline (Schnitker 1974; figure 2-18).

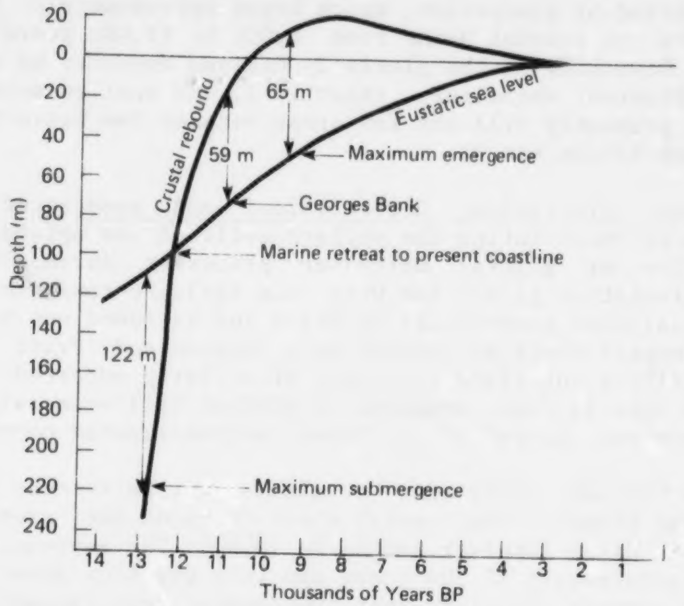


Figure 2-18. The relationship of eustatic sea level rise, crustal rebound, and subsidence to the geological characteristics of the Maine coastline.

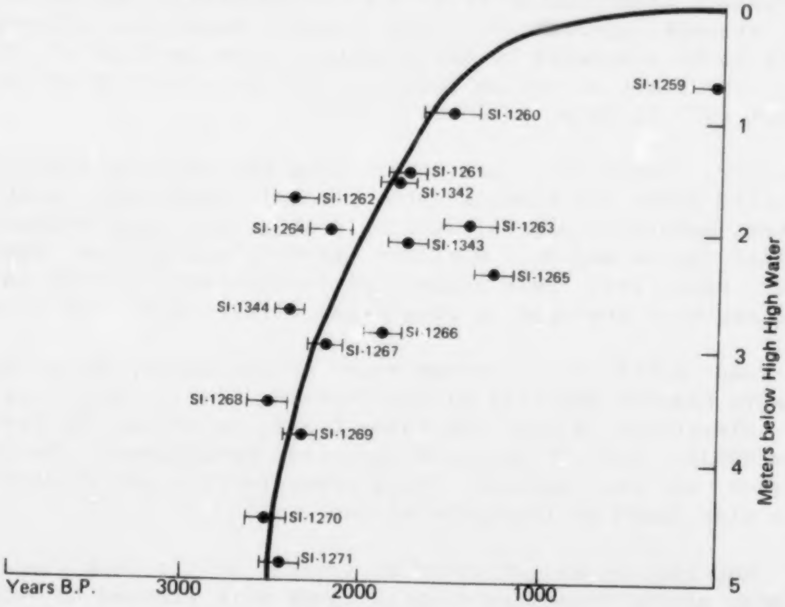


Figure 2-19. Sea level curve for Addison, Maine, derived from radiometric C^{14} dating of salt marsh peat (Thompson 1977).

During the period from maximum submergence to maximum emergence, rivers, streams, and other erosion agents dissected the coastal area upland and generated a land surface topography similar to today's (atlas map 3). Weathering and reworking of surficial glacial and glaciomarine sediments took place during the period of sea level rise from 8500 years ago to the present, creating the present shoreline. These processes have formed, and continue to form, the coastal marine sedimentary environments along the present shoreline (atlas map 3).

Holocene sea level rise. Sea level has been rising for the past 8500 years. It occurs through a combination of eustacy (world-wide rise of sea level due to the addition of glacial meltwater to the ocean's volume) and a depression of the coastal New England region land mass (Grant 1968).

Using C^{14} radiometric dating of buried salt marsh peat, Thompson (1977) found sea level rise 3000 years ago to be approximately 0.45 inch (1.15 cm) per year. This relative rise decreased to a rate of about 0.11 inch (0.06 cm) per year over the past 1000 years (figure 2-19).

Sea level rise rates for the past 40 years have been determined from tide-gauge records along the Maine coast (Hicks 1972; figure 2-20). Apparent trends of sea level rise at Portland and Eastport from 1940 to 1970 are 0.06 inch (0.16 cm) per year and 0.11 inch (0.34 cm) per year respectively (Hicks 1972). A minor portion of the present rise is due to eustatic sea level rise; most of the rise is apparently due to crustal subsidence of the Maine coast. The reason for this subsidence is unknown.

For the past 8.5 millenia, the sea has been advancing upon coastal regions. Concomitantly, normal subaerial weathering, both chemical and mechanical, has continually eroded the Maine upland region. The end result of upland erosion is the delivery of riverborne and streamborne sediment to the shoreline or to closed depressions (lacustrine and palustrine systems) on the terrestrial landscape.

In summary, the geological framework of the Maine coast is a mosaic of two geological elements: (1) a consolidated and unconsolidated complex outline of bedrock and glacial deposits, and (2) recent sedimentary deposits on the bedrock and glacial deposits. Both elements are being continually changed by erosion and deposition resulting from coastal forces and a rising sea level.

Erosion and sedimentation. Rapid erosion and sedimentation of nearshore environments alters the substrata and creates stresses on plants and other organisms, including people, that utilize these substrates. Natural erosion and deposition create beaches and dunes for human recreation, intertidal areas for marsh and shellfish growth, and natural channels for navigation.

Fine-grained sediment is introduced to the nearshore zone by rivers discharging into estuaries, by sediment reworking within the basin, and by floor sediments from the inner Gulf of Maine. Sediment loads of rivers discharging into heads of estuaries during normal discharge periods vary from <0.9mg/l to about 12 mg/l (U.S. Geological Survey 1976). Sediment loads after spring freshets may be 40 mg/l. These loads correspond to daily suspended sediment discharges of from 29 tons (26 t) per day to 3270 tons (2943 t) per day. Calculations based on sediment yields from soil erosion indicate that

64,968 tons of sediment are delivered annually to the nearshore area northeast of Casco Bay. Total organic carbon discharges as particulate matter range from about 5 mg/l to 12 mg/l and do not appear to vary seasonally (U.S. Geological Survey 1976). Schnitker (1974) reported that under normal meteorological conditions suspended sediment concentrations entering estuaries from the ocean are about 2 to 2.5 mg/l. During storm periods, this concentration increases to 6 mg/l. Schnitker's (1972) studies in Montsweag Bay, the Sheepscot River estuary, indicate that sediments derived from within the basin normally reach concentrations of about 6 mg/l. If the normal discharge concentrations (about 1 mg/l) entering the estuary from rivers are subtracted, it becomes evident that about 5 mg/l of concentrate is derived from within the basin. This sediment remains within the nearshore area as redeposited material. Suspended sediment concentrations of bottom waters within the estuary may exceed 10 mg/l during and immediately after storm periods. Schnitker (1972) reported that these values of sediment flux resulted in a net deposition rate of 0.7 to 1.1 inch (1.9 to 2.8 cm) per year in Montsweag Bay. These figures probably are applicable to most of the intertidal nearshore area. The nearshore sedimentation of fine-grained sediments, coupled with an ongoing sea level rise of approximately 0.08 to 0.14 inch (0.22 to 0.36 cm) per year (Hicks 1972) results in a sediment wedge accumulating at the nearshore, which will migrate landward (figure 2-21).

Shoreline erosion. Shoreline erosion along the Maine coast has been documented by Timson and Kale (1977). Erosion of unconsolidated shorelines is dependent on several factors including: the amount of wave energy impacting the shoreline, the type of unconsolidated sediment existing at the shoreline, shoreline orientation, and the influence of people. Natural erosion of unconsolidated shorelines is occurring at a rate of about 0.5 to 2 feet (15 to 61 cm) per year along the coast. Many beaches are eroding at greater rates, primarily due to the influence of protective engineering structures and navigation works. The highest rate of shoreline erosion occurs at Hunnewell Beach, Phippsburg, at the mouth of the Kennebec River. Timson (1977) attributes this high erosion rate to dredging in the Kennebec River estuary between the river mouth and the city of Bath.

Acceleration of erosion rates, to recession rates of up to 90 feet (27 m) per year, is caused by disruption of normal sand transport pathways by the removal of channel bar sediment from the estuary floor. Offshore disposal or disposal of sediment elsewhere within the estuarine system has disrupted the rate of delivery of sediment to the Popham Beach area. Supporting evidence for this disruption includes:

1. Hunnewell Beach was progradational until 1940. Dredging of the Kennebec began in 1942 and recurred at intervals of 2 to 4 years. Hunnewell Beach became recessional with the commencement of dredging.

2. The volume of sand lost from Hunnewell Beach from 1940 to 1974 approximates the amount of material dredged from the estuary during the same time interval.

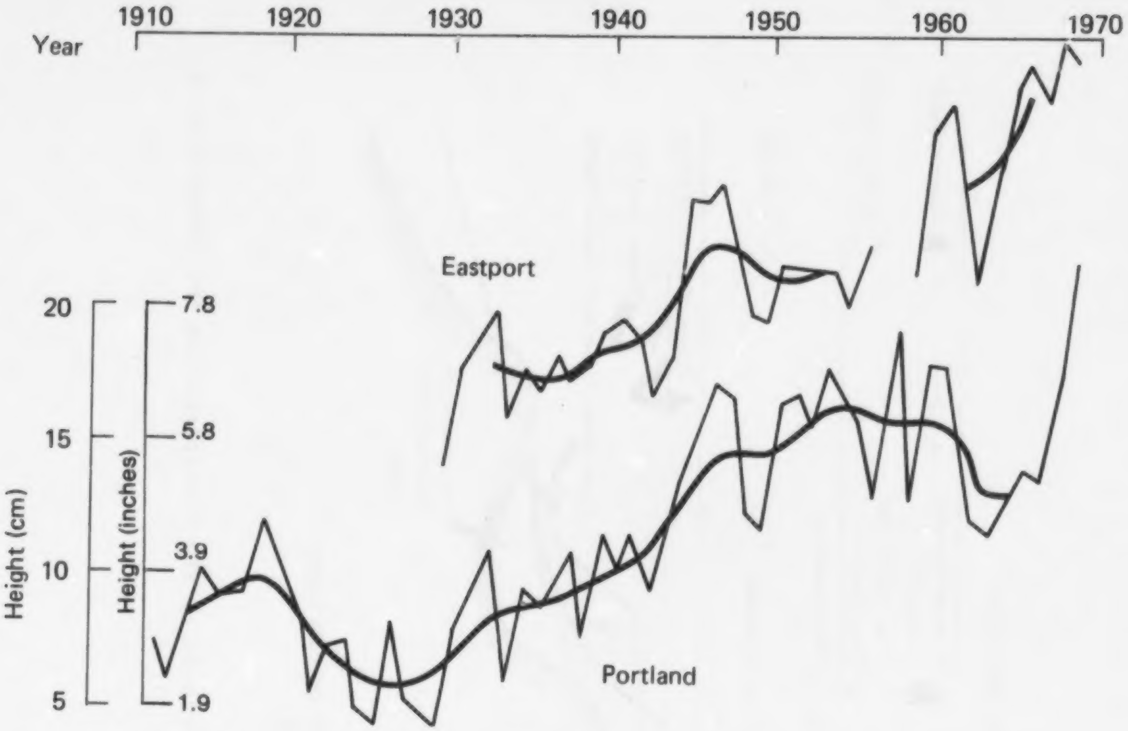


Figure 2-20. Sea level rise at Eastport and Portland over the past 40 years. Sea level is rising at a rate of 0.36 cm (0.14 inch) per year at Eastport and 0.22 cm (0.08 inch) per year at Portland (Hick 1972).

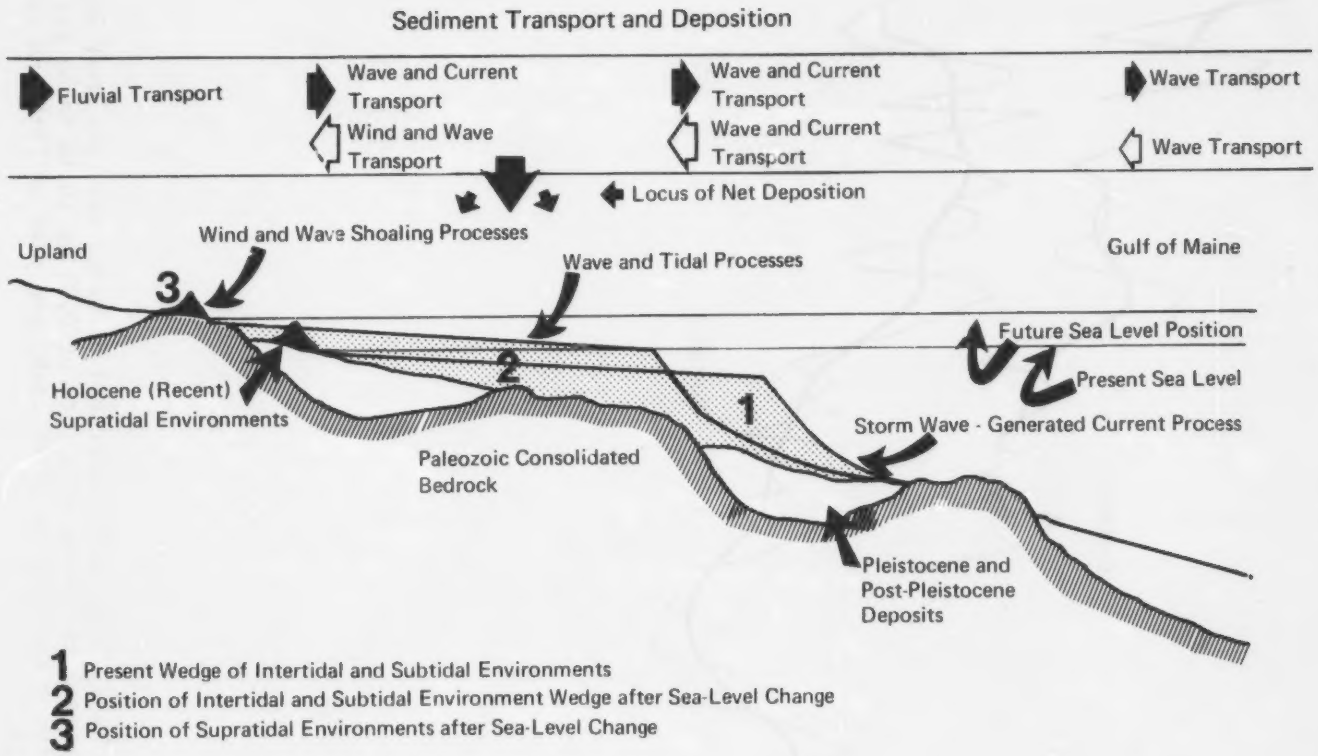

Sediment Transport and Deposition
Fluvial Transport
Wave and Current Transport
Wind and Wave Transport
Wave and Current Transport
Wave and Current Transport
Wave Transport
Wave Transport
Locus of Net Deposition
Upland
Wind and Wave Shoaling Processes
Wave and Tidal Processes
Gulf of Maine
3
2
1
Future Sea Level Position
Present Sea Level
Holocene (Recent) Supratidal Environments
Storm Wave - Generated Current Process
Paleozoic Consolidated Bedrock
Pleistocene and Post-Pleistocene Deposits
1 Present Wedge of Intertidal and Subtidal Environments
2 Position of Intertidal and Subtidal Environment Wedge after Sea-Level Change
3 Position of Supratidal Environments after Sea-Level Change

Figure 2-21. The processes and interactions that contribute to the transportation and deposition of nearshore sediment (modified from Timson 1977).

Surficial geology and soils. The substrate of terrestrial habitats is either bare bedrock or unconsolidated surficial deposits derived from glacial drift. Exposed bedrock is predominant in the coastal zone in ridge tops, coastal mountains, and islands. Bedrock surfaces constitute a substantial portion of the terrestrial habitat in Lincoln, Sagadahoc, Knox, Hancock, and Washington Counties. Exposed bedrock is obviously inhospitable to plant growth and to most types of human activity.

The unconsolidated surface deposits, however, present a variety of substrate surfaces by virtue of the variable characteristics of the glacial, glacial-related, and postglacial deposits from which surface soil textures are derived. Because deglaciation along the Maine coast was accompanied by marine submergence and local glacial readvances (Stuiver and Borns 1975; and Bloom 1963) the distribution and stratigraphy of the coastal surficial deposits are complex and varied. A generalized stratigraphy for the coast can be recognized, however, and related to terrestrial topography.

Lower elevations on the upland are characterized by glacial till above bedrock, covered by marine silts and clays of the Presumpscot Formation. Unsorted and stratified tills in the form of moraines sometimes lie on and within the fine-grained marine deposits (figures 2-22 and 2-23).

Elevations above 290 feet (88 m) and below higher ridge and mountain elevations are characterized by basal till deposits overlain by stratified glacial-stream deposits. At elevations from 240 to 350 feet (73 to 107 m), late glacial beach, spit, and delta sands and gravels mark the highest elevations of marine incursion (figure 2-24).

Ridge flanks, coastal mountain tops, and most of the coastal islands are characterized by bare ledge or thin glacial tills, both basal and ablation (Thompson 1977).

At all elevations, topographic depressions are filled and are filling with wetland organic deposits (figure 2-25).

Coastal zone surface soils are derived from the bedrock or glacial-derived inorganic deposits. Organic soils are classified according to parent material, relief, and drainage (Bushnell 1942). Rourke and coworkers (1977) recognize three major and four minor soil types present in the coastal zone. The three major types and their characteristics are:

1. Peru-Marlow-Lyman. This soil association represents Spodosols: mineral soils in which iron, aluminum, and organic matter have been leached from surface soil horizons and accumulated in lower horizons. The soils have formed in loamy glacial till and are distributed throughout Cumberland and Washington Counties. Peru and Marlow soils are deep, with restrictive, slowly permeable layers, and they occur on ridge slopes. Lyman soils are thin (25 to 50 cm thick; 10 to 20 inches), lie over bedrock, and occur on ridge tops and steep slopes.

2. Hermon-Lyman-Peru. These soils are Spodosols developed on glacial till. This association occurs in Washington and Hancock Counties. Hermon soils are deep, well drained, and often bouldery and occur on ridge tops and hillsides.

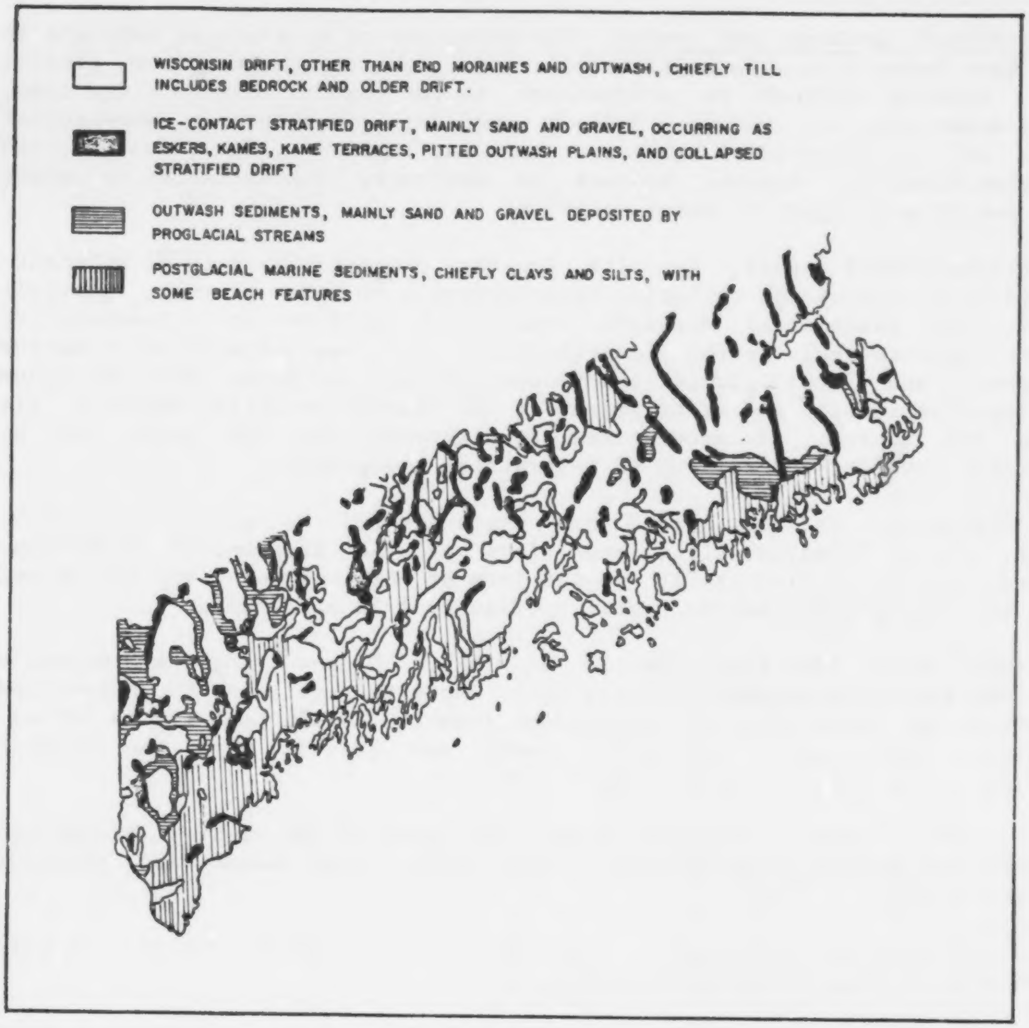

WISCONSIN DRIFT, OTHER THAN END MORAINES AND OUTWASH, CHIEFLY TILL INCLUDES BEDROCK AND OLDER DRIFT.
ICE-CONTACT STRATIFIED DRIFT, MAINLY SAND AND GRAVEL, OCCURRING AS ESKERS, KAMES, KAME TERRACES, PITTED OUTWASH PLAINS, AND COLLAPSED STRATIFIED DRIFT
OUTWASH SEDIMENTS, MAINLY SAND AND GRAVEL DEPOSITED BY PROGLACIAL STREAMS
POSTGLACIAL MARINE SEDIMENTS, CHIEFLY CLAYS AND SILTS, WITH SOME BEACH FEATURES

Figure 2-22. Surficial deposits in the coastal zone (Doyle 1967).

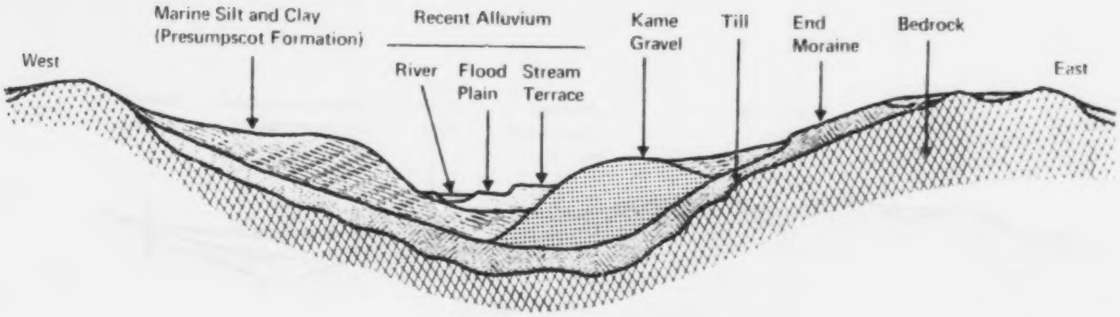

West
Marine Silt and Clay
(Presumpscot Formation)
Recent Alluvium
River
Flood Plain
Stream Terrace
Kame Gravel
Till
End Moraine
Bedrock
East

Figure 2-23. Generalized cross section of surficial deposits in the Kennebec River valley from Augusta to Pittston (Thompson 1977).

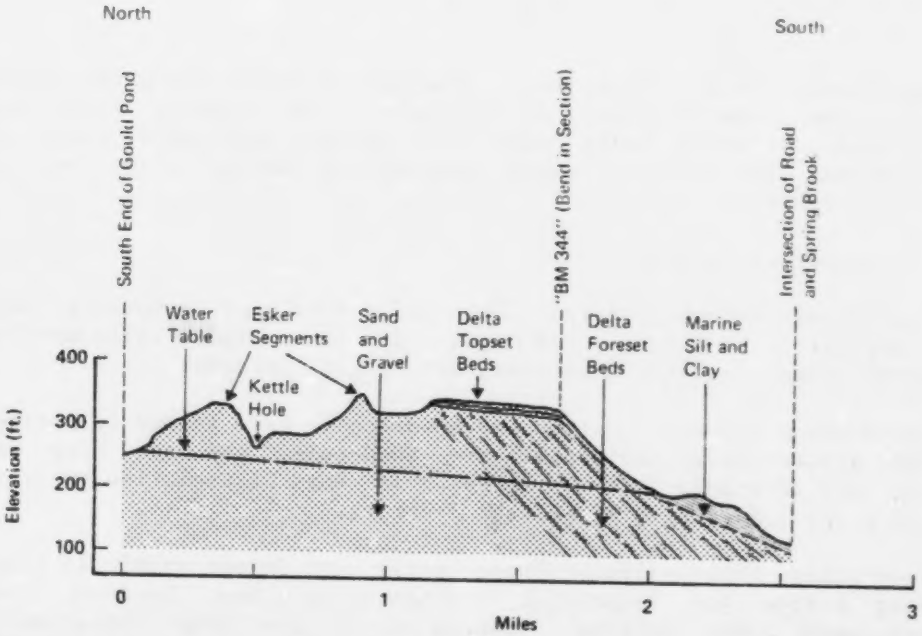

North
South
South End of Gould Pond
"BM 344" (Bend in Section)
Intersection of Road and Spring Brook
Water Table
Esker Segments
Kettle Hole
Sand and Gravel
Delta Topset Beds
Delta Foreset Beds
Marine Silt and Clay
Elevation (ft.)
400
300
200
100
0
1
2
3
Miles

Figure 2-24. Cross section of esker and glacial-marine delta west of North Augusta, showing the internal structure of the delta and the general profile of the water table (Thompson 1977).

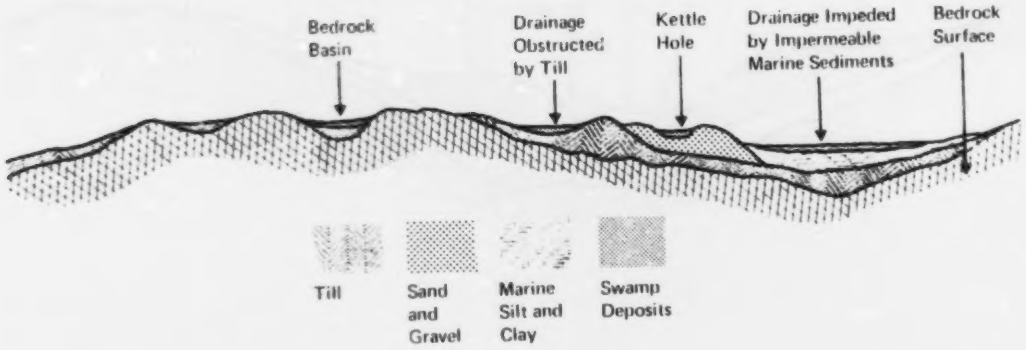

Bedrock Basin
Drainage Obstructed by Till
Kettle Hole
Drainage Impeded by Impermeable Marine Sediments
Bedrock Surface
Till
Sand and Gravel
Marine Silt and Clay
Swamp Deposits

Figure 2-25. Cross section of several types of wetland deposits on inland topographic depressions.

3. Lyman-Scantic-Peru. This soil association occurs along the entire coastal zone from Portland to Eastport. The Scantic soils are Inceptisols, mineral soils that have weakly expressed zones of alluviation. The Scantic soils develop on marine clays on low elevation surfaces.

The minor soil associations are:

1. Lyman-Histosols-Rock Outcrop. Thin soils developed on bedrock, thin till deposits over bedrock, and organic deposits. These soils develop on steep slopes, ridges, mountains, and coastal islands.

2. Colton-Adams-Histosols. Colton and Adams soils have formed in coarse-grained glaciofluvial sediments, are Spodosols, and are deep and excessively drained. The Histosols in this association occur in kettle holes and fringes of outwash deposits.

3. Buxton-Salmon-Nicholville. These soils have formed mainly in fine-grained marine and lacustrine sediments in the Kennebec and Androscoggin River valleys. Buxton soils are deep Inceptisols, moderately well-drained to poorly drained. Salmon and Nicholville soils, Spodosols, are deep, moderately well drained soils having alternating layers of very fine sandy loam and silt loam.

4. Scantic-Buxton-Adams. Soils developed above the floodplain of the Royal River. Adams soils develop in sand deposits and are deep, excessively drained, and sandy. Adams soils are Spodosols.

Surficial deposits and their attendant surface soils provide physical substrates capable of supporting a variety of elements: forests, wildlife, agriculture, and other human activities. Information on the major coastal soils is available from the U.S. Department of Agriculture Extension Agents in coastal counties.

To maintain an optimum level of ecological suitability in soils, a balance must be sustained between erosion and accumulation. Soils accumulate by addition of material to the soil column surface or by the breakdown of parent material at the column base. The latter mode of gain is extremely slow in temperate latitudes. Soil gains are primarily restricted to addition of organic matter as litter or decomposing vegetation in terrestrial environments, organic growth and sedimentation in palustrine environments, and inorganic sedimentation on alluvial floodplain soils. Rates of soil gain in coastal Maine are unknown.

Soil losses can be attributed to natural surface erosion by sheet wash, streambank erosion, and slope failure. People have upset the soil balance in certain areas of coastal Maine by a variety of activities. Rates of soil loss are discussed in chapter 3, "Human Impacts on the Ecosystem."

Hydrology

The distribution, chemistry, and movements of surface waters and groundwater are important determinants of surficial deposits. Together these geological and hydrological factors influence the development of plant and animal communities and affect human land use.

Groundwater. The occurrence, movement, quality, and retrievability of groundwater in the coastal zone are major driving forces of human, plant, and animal population dynamics. In Maine, the abundance and availability of groundwater are primarily determined by the level to which groundwater will rise, the nature and distribution of unconsolidated surficial deposits, and the distribution of bedrock fractures (Caswell 1977).

Aquifers are storage deposits for groundwater. They receive water from precipitation or from surface water entering the substrate at the aquifer's recharge area. The major aquifers in Maine are restricted to surficial deposits of coarse-textured sand and gravel and to major fracture systems. Recharge areas for aquifers are coarse-grained surficial deposits of large areal extent.

Acquiring groundwater for human use, either municipal or commercial, without disrupting wetland ecology requires knowledge of a region's groundwater characteristics. This is necessary to prevent contamination of groundwater supplies from surface waste disposal activities. Basic information about groundwater in coastal Maine will be reviewed below. Regional data are discussed in appendix D.

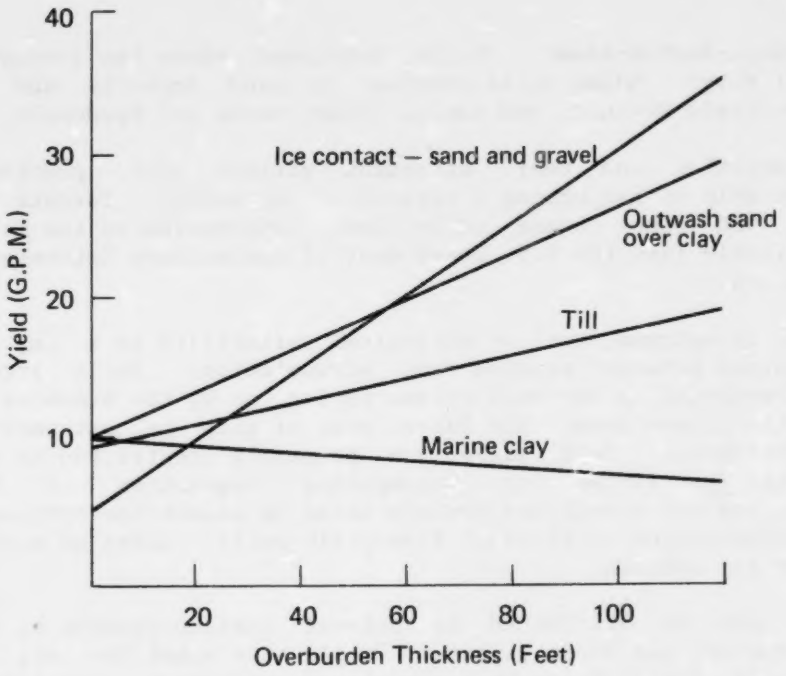


Figure 2-26. Relationship between bedrock well yield and thickness and type of surficial overburden in the coastal zone (G.P.M. = gallons per minute; Caswell 1977).

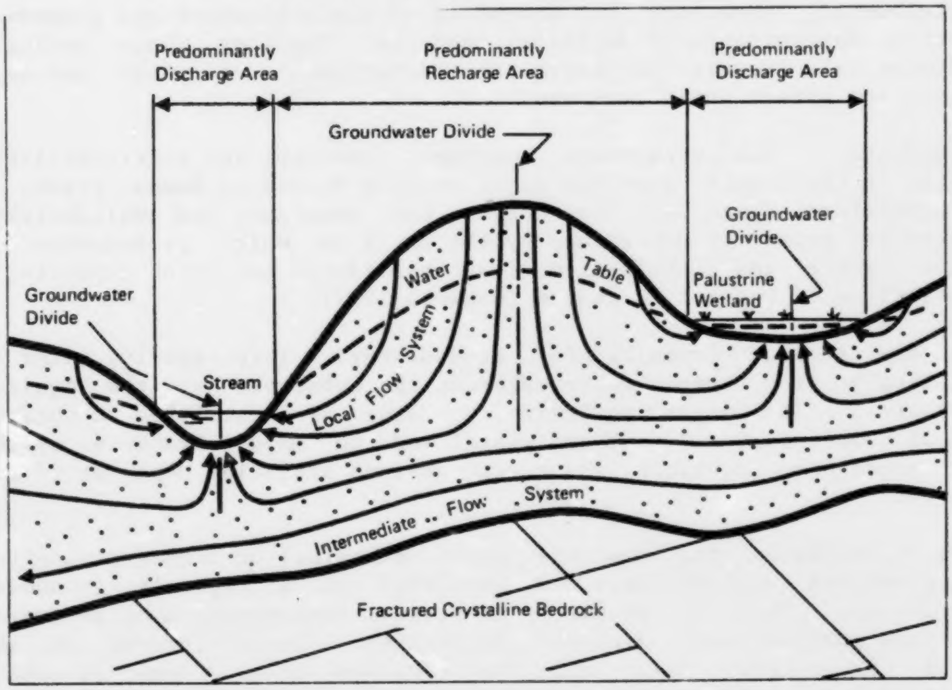

Predominantly Discharge Area
Predominantly Recharge Area
Predominantly Discharge Area
Groundwater Divide
Groundwater Divide
Groundwater Divide
Palustrine Wetland
Water Table
Stream
Local Flow System
Intermediate Flow System
Fractured Crystalline Bedrock

Figure 2-27. Generalized groundwater flow in unconsolidated sediment systems. (Caswell 1977).

Overburden thickness and bedrock surface topography. The type and thickness of the unconsolidated material that overlies the bedrock and the corresponding yield of groundwater are depicted in figure 2-26. Thick, permeable, and saturated overburden supplies groundwater to shallow wells and recharges water to underlying bedrock aquifers. Figure 2-26 can be used in conjunction with surficial geological maps to estimate the relationship between the thickness and type of surface materials and water yield. Caswell (1977) has found a strong correlation between types of overburden material and bedrock well yield.

Because most water purification processes take place in the unconsolidated sediments overlying the bedrock, local bedrock aquifers in thinly overburdened areas are more susceptible to pollution from surface sources of contamination. For this reason, waste disposal areas are least acceptable on thinly covered bedrock.

Information about the distribution of bedrock surface elevation is used to determine probable groundwater flow in the overburden just above bedrock. Groundwater in overburden generally flows at right angles to the bedrock surface contours.

Potentiometric surface of bedrock wells. The elevation to which groundwater will rise in an artesian well drilled into the bedrock aquifer is defined as the potentiometric surface. A map of this surface indicates the potential for groundwater flow in the bedrock from any point to any other point. The physical properties of bedrock vary from area to area and groundwater flow has been shown to depend more upon bedrock fracture patterns than upon bedrock characteristics. Potentiometric surface maps, available from the Maine Geological Survey, represent ideal flow conditions showing that high flow potentials occur at topographic highs and that low flow potentials generally occur in topographic valleys (figure 2-27). Valleys tend to be areas of groundwater discharge, while high elevations and slopes are recharge areas. Groundwater divides generally coincide with topographic divides.

Potentiometric surface maps could be used to predict flow characteristics of groundwater systems, taking into account the fact that fracture systems will affect groundwater flow differently than the flow potential surfaces indicate. A knowledge of the local fracture system is therefore necessary to determine general groundwater conditions.

Ground and surface water contamination. Contamination of ground and surface water supplies occurs through natural flux of particulates and dissolved ion species, direct introduction of wastes into water bodies, and introduction of contaminants through surface soil runoff.

Natural contamination of groundwater supplies has been documented by Caswell (1977), who lists the following occurrences of contamination in the Maine coastal zone:

1. Salt water intrusion in fracture-controlled aquifers occurring near the ocean (figure 2-28).

2. Salt water contamination of wells penetrating possible Permo-Triassic salt deposits or entrapped marine water originating during postglacial sea-level stands.
3. Salt contamination of wells located in the proximity of heavily salted highways during winter and spring months.
4. Mineral contamination of well water from dissolved ions originating from the bedrock. These ions include high iron, sulfide, and calcium-magnesium derived from schists and metamorphised limestones, radon from high radium-bearing igneous granites, and toxic heavy metals (e.g., copper, zinc, mercury) from ore-bearing rock bodies.

Toxic heavy metal concentrations occur in ground or surface waters where base-metal ore-bearing rock bodies occur. The Union-Warren and Blue Hill-Cape Rosier drainage areas exhibit relatively high concentrations of metals (e.g., copper; Hurst and Dow 1972) which may contaminate or be toxic to commercial marine organisms in the estuarine areas that receive their discharge.

Other contaminants of water supplies and coastal waters are introduced through direct application of solid and liquid wastes, pesticides, and sewage onto or within surface soils. Leachates from solid waste disposal sites, settling lagoons, individual septic systems, farm feed lots, and pesticide application to agricultural and forested lands have all been documented as having contaminated ground or surface waters (Caswell 1977; see chapter 3, "Human Impacts on the Ecosystem").

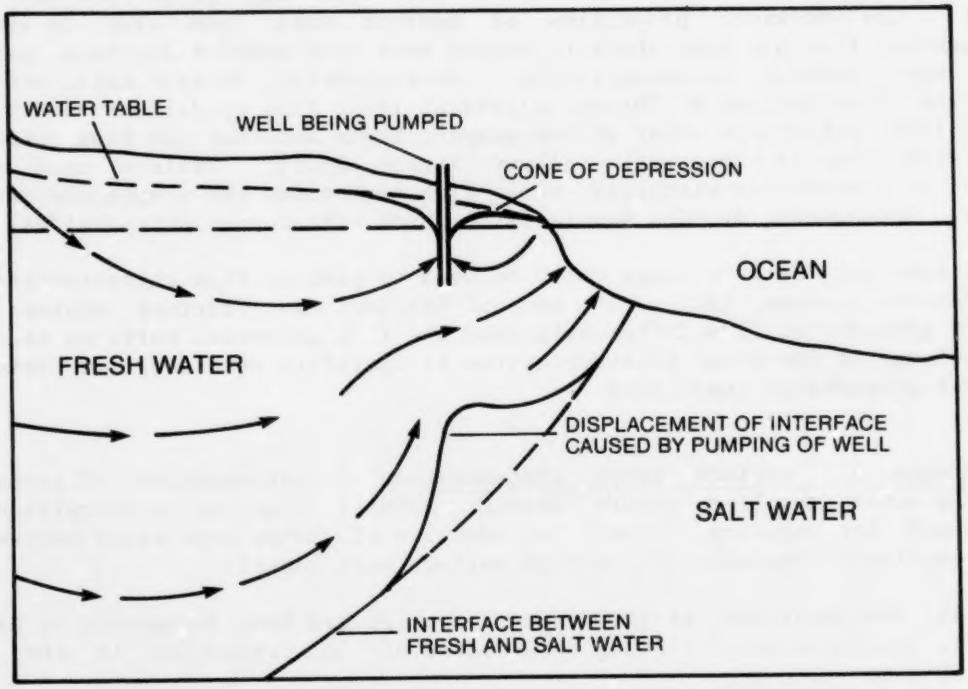

WATER TABLE
WELL BEING PUMPED
CONE OF DEPRESSION
OCEAN
FRESH WATER
DISPLACEMENT OF INTERFACE CAUSED BY PUMPING OF WELL
SALT WATER
INTERFACE BETWEEN FRESH AND SALT WATER

Figure 2-28. Groundwater flow near the fresh water - salt water interface and the effect of pumping a well (Caswell 1977).

Research needs in geology and hydrology. This discussion is limited to geology as it is related to ecology; thus, gaps in the knowledge of the origin of bedrock units are not discussed. Data gaps in bedrock, surficial deposits, soils, marine and riverine sedimentation, and hydrology are assessed below:

1. Bedrock: The distribution of bedrock types within the characterization area has been well defined with the possible exception of the composition of the bedrock underlying the outer islands. Little is known about the submerged bedrock platform extending to the seaward limits of the characterization area. Of particular interest concerning the latter fact is the potential for commercial mineral mining in the shallow subtidal areas. The mineral potential of terrestrial bedrock is fairly well known.

The trace element content of plutonic rocks has been given much attention in recent years, especially the radiogenic elements and the faults and fractures (planes of separation and previous movement) that cut through consolidated bedrock. The interest in the former centers around the amounts of radiogenic material (available as uranium) and geothermal energy for power generation and the amount of radon in the atmosphere. Radon in its gaseous form may be a carcinogenic contaminant of groundwater supplies. Federally sponsored research is now being undertaken to fill gaps in the data available on these radiogenic elements, and some State and Federal research is being conducted to answer questions on past fault movement during earthquakes and on the influence of bedrock fractures on groundwater flow. More work, however, is needed to meet knowledge needs in relation to seismicity and groundwater flow through fractured bedrock.

2. Surficial deposits: Knowledge of the distribution of surficial deposits is adequate. Knowledge of the three-dimensional nature of these deposits is lacking, however. It is known that much of the coastal area consists of glacially derived sands and gravels under marine clay deposits, but the distribution, thickness, and lateral extent of these coarser deposits are largely unknown, except where specific engineering evaluations have been conducted.

Knowledge of these deposits is necessary in solid waste disposal, aquifer identification and protection, evaluation of pesticide contamination of surface and groundwaters, and location of future sand and gravel resources.

The extent and volume of peat resources have become significant because of the energy potential of peat. The resource volume in coastal Hancock and Washington Counties is known, but Waldo County has many bogs that have not been investigated as yet. Much also remains to be learned of the growth rate of peat and the hydrology of peat bogs.

3. Soils: Although the distribution of soils in the characterization area and their general suitabilities for human activities are well known, the knowledge of rates of formation and erosion are controversial. More knowledge, especially on agricultural and forested soils, is needed.

4. Sedimentation: Sedimentation in marine, estuarine and riverine environments is poorly known. A general knowledge of the behaviors of such deposits in other areas has been acquired. Knowledge of suspended sediment

loads and bedload is needed in coastal rivers. Except for a few measurements by the USGS (1978) virtually nothing is known about river sedimentation. Substantial knowledge of riverine morphology and processes, especially those of tributary streams that undergo changes in response to human activities, also is lacking. Knowledge of suspended transport, deposition and erosion rates, and bedload transport in estuaries is severely lacking. Such information is valuable in evaluating impacts on dredging, aquaculture, and commercial fishing. This also applies to marine sedimentation.

One of the most pressing geological problems within the coastal zone is the problem of shoreline erosion. Recent attention to this problem has produced a general knowledge of shoreline behaviors, but the predictability of future erosions will require further investigation. More information on beach sedimentation, especially transport budgets, will be required to properly manage these valuable resources.

5. Hydrology: The viability of groundwater resources has become a major concern, because of the increased volume requirements of industrial and residential use and the increased knowledge of contamination possibilities. While past activities of the MGS and USGS have given us a far better knowledge of surface and groundwater hydrology than ever before, much more information is required to fully understand the behavior of groundwater and its relationships to surface water hydrology.

Further knowledge is needed in locating surface aquifers and discerning their characteristics. Little is known about the transport rates and flow directions of groundwater in bedrock fractures. Groundwater recharge and replacement rates need study and more knowledge of regional and local groundwater systems is necessary.

The Socioeconomy

Coastal Maine is a predominantly rural, forested area with a population density that is low in comparison with the remainder of New England. The coastal waters and physiographic features of the land have strongly influenced the pattern of growth and development of the coastal zone. The inland areas of the characterization area (northern parts of regions 2 and 4) are more urban than coastal areas. The population centers of Augusta and Bangor are located relatively inland in river valleys. However, Maine's largest urban area, Portland, is located in the southwestern coastal region of the characterization area (region 1). In general, the more populous areas are located in the western part of the characterization area, whereas the easternmost regions are the least populated and least developed.

In comparison with other areas, the demands placed on the Maine coast have until recently produced only moderate changes. The small and generally scattered population has had limited ecological impact. More recently, large areas of the coast have begun to change rapidly. These changes and the socioeconomic pressures on the coast are explored below.

Analysis of the socioeconomic characteristics of coastal Maine has been hindered by a scarcity of information. In this characterization, the boundaries of the study area coincide with the area of tidal influence. In the State of Maine, socioeconomic data are usually collected by county or by the State as a whole. Since the coastal counties in Maine usually extend beyond the inland border of the characterization area, information specific to the coastal area is not readily available. In addition, the data describing each socioeconomic sector are not comparable: data for similar time periods are not available for each sector, and available data were collected for different purposes. As a result, the relative value (e.g., in dollars or persons employed) of each sector (e.g., fishing, agriculture, and forestry) in the coastal Maine economy is difficult to determine.

Commercial fishing, forestry, agriculture, mineral extraction, sport fishing, hunting, and trapping are the socioeconomic sectors that directly harvest the region's resources. Other socioeconomic sectors, including transportation, industry, and recreation, alter habitats (wetlands impounded or filled or forests cleared) and generate wastes (discharge effluents into the ecosystem). The impacts of socioeconomic activities on the ecosystem are described in chapter 3, "Human Impacts on the Ecosystem."

Fisheries. Fishing and shore-based fish processing industries constitute a large portion of coastal Maine's economy. The Maine Department of Marine Resources (MDMR) estimates that the total annual value of marine fisheries in Maine is over $300 million (C. E. Maguire, Inc.1978; includes the entire coast from Eastport to Kittery).

The landed weight of many species has declined over a 20-year period, while the landed value (unadjusted for inflation) has continued to increase, especially in the lobster and clam fisheries. A comparison of landed weights and values during selected years over a 20-year period is shown by species in table 2-12. The locations of areas important to fish and shellfish harvest in coastal Maine are illustrated on atlas map 4.

Of approximately 14 species of fishes reported in the landings, sea herring and ocean perch have comprised 70% of the total weight in recent years. These and five other low value species account for 90% of all landed finfish by weight. Highly valued species, such as cod, halibut, and haddock, amount to only 5% of the total landed weight. Distance from major markets, lack of adequate shore-side processing, and competitively lower prices elsewhere in New England have contributed to the fishery's lack of growth (C.E. Maguire, Inc. 1978).

Lobster is the most valuable fishery in coastal Maine. Lobster landings have declined from 22 million pounds in 1955 to 19 million pounds in 1976, yet their value has doubled from $16 million to $32 million (in 1977). In the characterization area approximately 7000 lobster licenses were issued, 4600 boats were in operation, and approximately 650,000 traps were fished in 1976 (Maine Department of Marine Resources 1976).

The clam fishery is second in value to lobsters. Due to the extent of intertidal habitat and the low pollution levels in flats in eastern Maine, the clam industry increases in value progressively towards Washington County (region 6), where nearly half of the landed soft-shelled clams are harvested. Regions 5 and 6 accounted for 73% of the 1977 clam harvest (Maine Department of Marine Resources 1977). However, according to the same source, a serious decline was noted in clam harvest, especially in Hancock County (regions 4 and 5). As a result, conservation measures, such as town clam ordinances, have

Table 2-12. Species Weight (pounds x 1000) and Values (thousands of dollars; in parentheses) of Landing Between 1955 and 1976 in Coastal Maine[a].

Species	Years				
	1955	1965	1970	1975	1976
Alewives	3779 (62)	3106 (67)	1623 (51)	3768 (134)	3395 (112)
Bloodworms	203 (313)	770 (1165)	845 (1529)	638 (1779)	532 (1255)
Clams, hard-shelled	499 (49)	3 (3)	8 (12)	8 (16)	3 (5)
Clams, soft-shelled	2621 (1776)	1964 (1478)	5259 (3141)	6529 (5671)	7368 (7489)
Cod	2467 (264)	2629 (198)	5427 (449)	4560 (647)	3249 (590)
Crabs	499 (49)	2530 (115)	1571 (113)	938 (79)	1152 (162)
Cusk	603 (64)	286 (25)	266 (24)	721 (92)	862 (147)
Eels	33 (11)	52 (18)	38 (11)	154 (83)	191 (94)
Flounder	3534 (460)	1648 (126)	1623 (177)	2711 (730)	3610 (1226)
Haddock	4009 (517)	1881 (282)	1013 (232)	776 (273)	1357 (733)
Hake	2398 (193)	3849 (195)	1411 (94)	4560 (365)	5532 (601)
Halibut	134 (69)	93 (49)	52 (31)	45 (48)	48 (60)
Herring	99,416 (2534)	70,180 (1791)	36,593 (822)	38,248 (1423)	70,233 (3053)

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[a] Maine Department of Marine Resources 1955-1976 and 1977.

(Continued)

Table 2-12. (Concluded)

Species	Years				
	1955	1965	1970	1975	1976
Lobsters	22,718	18,862	18,172	17,017	19,001
	(16,322)	(21,744)	(21,637)	(27,479)	(29,238)
Mackerel	1011	670	482	145	405
	(148)	(65)	(27)	(22)	(81)
Mussels	105	32	301	612	1203
	(5)	(5)	(81)	(197)	(344)
Ocean perch	67,685	60,307	46,688	21,503	25,783
	(4827)	(3650)	(2860)	(1979)	(2604)
Pollock	5052	1093	811	5917	7717
	(234)	(73)	(62)	(547)	(874)
Sandworms	179	739	747	748	698
	(207)	(686)	(782)	(863)	(812)
Scallops	1114	414	180	1594	629
	(1087)	(443)	(272)	(3019)	(1352)
Sea urchins	58	N.A.	60	42	36
	(3)		(4)	(3)	(2)
Seaweed, moss	125	2895	2538	2330	4000
	(5)	(78)	(96)	(93)	(160)
Shrimp	0	2075	17,004	7005	1361
		(373)	(4417)	(1938)	(488)
Smelt	127	199	82	92	80
	(72)	(70)	(23)	(28)	(28)
Tuna	26	91	62	167	72
	(6)	(12)	(5)	(62)	(27)
Whiting	25,114	27,722	14,837	1198	408
	(498)	(745)	(1490)	(72)	(29)
Total weight	243,509	204,090	157,693	122,026	158,925
Total value	$29,775	$33,456	$38,442	$47,642	$51,566

been enacted in an attempt to recover overdug areas (see chapter 12, "Commercially Important Invertebrates"). The amount of clams harvested and the value of specific clam flats is available from MDMR but most of these data are not current. The locations of the major shellfish beds harvested in coastal Maine are shown in atlas map 4.

Additional species of importance, in order of value, are: bait worms (bloodworm and sandworm), $2.0 million; scallops, $1.3 million; and mussels, $0.3 million. In total, shellfish were worth $41.4 million, compared to $10.3 million for finfish at 1976 landed values.

The Department of Marine Resources has attempted to market and develop interest in such species as spiny dogfish, mussels, squid, eels and elvers, sea urchins, skate, quahogs, periwinkles, sculpin, pollock, and sea moss. Some of these species may have local economic value.

Sea moss (Irish moss) forms the basis of an industry, Marine Colloids, Inc. of Rockland, the world's largest producer of carrageen products (food stabilizers). Much of the sea moss comes from the Maritime Provinces of Canada. Little organized harvesting is done in Maine. Other related industries are boat-building and repair, trap mills, shellfish transporters, lobster cooperatives, and seafood wholesalers and retailers.

Aquaculture. Aquaculture and its commercial potential has received much attention on the Maine coast following the efforts of several groups (Gaucher 1971) to stimulate experimental work. Emphasis was placed on the salmonid fishes and oysters (*Crassostrea virginica* and *Ostrea edulis*). Although more than a hundred potential sites have been identified by the Maine State Planning Office (1977) only about ten active commercial projects exist in the characterization area. Descriptions of the feasibility and success of several of these projects are given by Merrill (1978), Mant (1974), and Hidu (1974).

Forest industry. The availability of useful data on the harvest and value of forest lands in the coastal zone varies considerably. About one-quarter of the State's commercial forest land, or 8,383,500 acres (3,394,120 ha), is in the coastal counties. Over 8484 million board feet of sawtimber, pole timber, and other materials were produced in the coastal counties in 1974. The Maine Bureau of Forestry estimates that the annual value of stumpage is approximately $245/acre in coastal Maine.

The forest industry owns 110,847 acres (44,610 ha) of land in Washington County, which constitutes 23% of the county's coastal land. This land is owned by five companies. In Hancock County, the only other coastal county in Maine with a large area of forest industry-owned land, only 3.7% of the total land in coastal towns is controlled by forest companies. Small woodlot owners (<1900 acres; 770 ha) possess more commercial forest land than forest companies possess. The only data on small woodlot ownership are from Washington County, where about 34% or 163,300 acres (66,127 ha) of the coastal towns are in small woodlots.

Despite the fact that only a relatively small portion of commercial forest land is located in the coastal zone, the economic impact of the industry on the coast is substantial. In Washington County, harvesting is a major source of employment for the population. Accurate data on the extent of harvesting operations are unavailable, partly due to the diversity of ownership. The only major forest-product processing plant in the coastal zone is located in Bucksport, and employs more than 1100 people. Plants in Westbrook, Topsham, and Baileyville, which are located outside the coastal zone, employ residents of the coastal zone. In addition, environmental impacts of processing plants affect areas downstream and downwind in the coastal zone.

Forest products in the coastal zone are also used in lumber mills, lobster trap mills, Christmas trees and wreaths, and related products. No data are available on the extent of these uses. Chapter 19, "Commercial Forest Types," contains further information on forestry; chapter 9, "The Forest System," and chapter 3, "Human Impacts on the Ecosystem," include discussions of the effects of existing forestry activities on the environment.

Agriculture industry. Agriculture is a relatively small industry in coastal Maine. Less than 10% of the land in the coastal zone is used for farming. The percentage of land used for farming varies from 1.5% in Hancock County to 13.7% of the coastal townships in regions 3 and 4. The market value of farm products has been increasing in recent years. The size of the 3100 farms in coastal Maine in 1974 averaged 183 acres (74 ha). The gross farm income was $241 million in 1974. The percentage of land used for farming has decreased sharply during the past 30 years. In Washington County the number of farms decreased from 591 with 160,898 acres (64,359 ha) in 1964 to 277 farms with 88,000 acres (35,200 ha) in 1974. The number of active farms (cropland) in the county in 1979 was only 37, occupying 414 acres (166 ha; personal communication from Richard Howard, U.S. Soil Conservation Service, Machias, ME; March, 1979).

Agriculture in the coastal zone includes harvested crops (grain, vegetables, potatoes, blueberries, orchard fruit, and hay) and livestock pasture. The market value for farm production in the coastal counties of Maine in 1974 was approximately $71 million. Blueberry agriculture in Hancock and Washington Counties is important both in terms of crop yield and processing value. The blueberry industry operates only during summer but is a significant part of the coastal economy in regions 5 and 6. Based on the 1977 season, the value of the blueberry crop in the coastal towns of Washington and Hancock Counties was estimated to be $2.9 million. Chapter 10, "Agricultural and Developed Land" presents further information on agricultural land, including acreages of agricultural land and acreages of land occupied by individual crops.

Mineral industry. Mineral production on the coast, primarily in the form of sand and gravel for building construction and roads, was valued at about $37 million in 1975 and $42 million in 1977 (U.S. Department of the Interior 1978). In 1975, 9,875,000 short tons of gravel and sand were removed for construction purposes. The islands and coastal areas were once famous for quarrying of building stone, but most of these quarries have been abandoned, with the exception of open pit mines of limestone in Thomaston (region 4) and Portland (region 1). The most recent active copper mining operation (Blue Hill, region 5) was closed in 1977 as prices for copper and zinc dropped. Peat has been mined in coastal Maine, primarily in regions 5 and 6. In 1975, 4000 short tons of peat were removed at a value of $207,000. Peat harvesting is expected to increase in the future. Reports are available describing the size of the potential peat reserves in Hancock and Washington Counties (regions 5 and 6 ; Cameron 1975; Cameron and Massey 1978). Atlas map 3 illustrates the location of surveyed peat resources in coastal Maine.

Recreation industry. Recreation forms an important part of coastal Maine's economy. An estimated 6 million tourists enter Maine in a typical year whereas the resident population is only 1 million. Tourists use the coastal beaches, camping areas, and town recreation facilities.

Tourism and summer residency have long been an important part of the Maine coastal economy. The only attempt to estimate the summer population was made in 1972 by the Public Affairs Research Center (PARC) at Bowdoin College. The study used 1970 U.S. census data and made the following assumptions: (1) that all available accomodations were full; (2) that not all sleeping establishments were known; and (3) that overlaps occurred in counts of sleeping and eating establishments. This capacity, also known as peak seasonal population, was an estimate of the capacity of each town to support tourists. Estimates by the Maine State Planning Office (personal communication from R. Sherwood, Maine State Planning Office, Augusta, ME; February, 1979) indicate that an increase in seasonal population of 4.5% has occurred since the PARC report of 1972. Data from the PARC study show the differences in winter and summer populations by coastal regions. In general, the summer population grows by 47% in the characterization area, from a low of 11% in region 1 to 175% in region 5 (table 2-13).

Thirty-six state parks and 19 memorial parks are present along the coast, 14 of which are developed and supervised and three of which have camping grounds (atlas map 3). The Maine Bureau of Parks and Recreation (St. Pierre 1978) cites 19 beaches from Cape Elizabeth to Lubec that are significant recreationally (table 2-14). These facilities received over one million visitors (day use) in 1976, doubling the day use of coastal State parks since 1965. Other campgrounds along the coast also have experienced rapid growth. For example, Acadia National Park, Maine's only federally administered park, recorded 2.7 million visits in 1976, a 23% increase in 10 years.

The traditionally popular coastal communities for summer tourists in the characterization area include Boothbay Harbor, the Penobscot Bay area, and Bar Harbor. Many of these areas were the sites of large hotels built during the latter 19th century. These hotels have been replaced over time by motels, cottages, and camping vehicles.

The Maine coastline ranks among the highest in the nation in terms of private ownership of coastline with least public access. The actual amount of private and public ownership varies according to definitions of private, public, and "quasi public" lands. Shore land defined as public amounts to 139 miles (222 km) or 3.5% of the total on an acreage basis. The Maine State Planning Office (1978) maintains that if quasipublic lands, or those held privately by conservation groups that allow public benefit, were included, the figure might reach 4.1% of the total. Nevertheless, the available land open for public use and access is considerably less because of restrictive controls. Locations of quasi-public, State, municipal, and Federal lands are shown on atlas map 3.

Table 2-13. Winter and Summer Populations in Regions of Coastal Maine in 1970[a]

Region	Winter population	Summer population (peak seasonal)	Percentage increase
Region 1	120,000	133,000	11
Region 2	62,000	107,000	73
Region 3-4 (excluding Bangor-Brewer areas)	40,000	62,000	55
Region 5	25,000	69,000	175
Region 6	23,000	33,000	43

[a] Public Affairs Research Center 1972.

Table 2-14. Significant Recreational Beaches of the Characterization Area[a].

Beach	Municipality	Ownership	Accessibility
Crescent	Cape Elizabech	State	Public
Willard	South Portland	Municipal	Public
Andrews	Portland	State	Public (limited)
Little Chebeague	Portland	State	Public (limited)
Seawall	Phippsburg	Private	Limited
Popham-Hunnewell	Phippsburg	Private/State	Public
Reid	Georgetown	State	Public
Pemaquid	Bristol	Municipal	Public
Lincolnville	Lincolnville	Private/Mun.	Public
Pond Island	Brooksville	Private	Public
Sand	Bar Harbor	Federal	Public
Sandy River	Jonesport	Private	Limited
Roque Island	Jonesport	Private	Public (limited)
Roque Bluffs	Roque Bluffs	State	Public

[a] St. Pierre 1978.

Sport fishing, hunting, and trapping. The magnitude and value of sport fishing and hunting are difficult to assess in coastal Maine, as hunting harvest data specific to the characterization area are not collected and no data on sport fishing are available.

A total of 231,542 hunting licenses were purchased in Maine in 1978. Approximately 198,000 of these were sold to residents. No information is available on the number of hunters utilizing the coastal zone. Information on harvest of the game species of mammals is presented in chapter 17, "Terrestrial Mammals."

Duck stamps are required of all waterfowl hunters over 16 years of age. Current duck stamp sales in Maine average near 18,000. Another 1800 to 2500 persons under 16 also hunt ducks, which brings the total to 20,000 duck hunters. The total recreation days enjoyed by waterfowl hunters approximates 100,000 annually in Maine. More than 75% of the annual harvest of waterfowl in Maine occurs in the coastal counties. In coastal Maine, waterfowl hunters generate about $2.75 million annually. Waterfowl harvest data in coastal Maine are presented in chapter 15, "Waterfowl."

Statistics on salt water sport fishing are extremely difficult to obtain, as no Federal or State licensing is required for this activity. According to the Maine Department of Transportation (1977), a significant recreational fishery exists in the Maine coastal zone. Twenty-seven vessels are registered as carrying passengers for purposes such as saltwater sport fishing. These are located primarily in Portland (region 1), Boothbay Harbor (region 2), Bar Harbor (region 5), and Eastport (region 6). A much larger number of persons fish from small private boats and bridges during times of active runs of mackerel and bluefish.

During the period from 1968 to 1971, an average of 240,512 fishing licenses were purchased in Maine, 145,678 of which were resident licenses. The Atlantic salmon fishery, one of the most valuable in Maine, was nearly destroyed in the recent past but is now being restored in a number of coastal rivers (see chapter 11, "Fishes").

Approximately 4200 recreational trapping licenses were purchased in the State in 1978. Information on the harvesting of the furbearer species in the coastal zone is presented in chapter 17, "Terrestrial Mammals."

Economy. Employment figures (Maine State Planning Office 1978) record only employees covered under the Federal Insurance Compensation Act. Because of the provisions of this Act, fishery and agricultural employees are underestimated and self-employed individuals are not included in the figures.

The earliest period of Maine's economy, beginning in 1600, was closely tied to the development of natural resources, both for subsistence agriculture and fishing, and, more importantly, for the export of raw resources of timber, fur, and fish. Fish was the major export in the 17th century, followed by white pine lumber for spars and masts for the Royal Navy. These uses of natural resources paved the way for the subsequent development of industry, when another coastal Maine resource, falling water, was harnessed during the industrial revolution to provide inexpensive energy.

Most of Maine's industrial manufacturing has been concentrated in six major industries. These are textiles, lumber and wood, transportation equipment, food, paper, and leather. All of these industries began in the 19th century and with the exception of leather experienced their greatest growth by 1930. This maturing of the industries came about because of changing markets, interregional competition, the depletion of raw resources, higher costs of energy and transportation, and aging facilities. As a result, Maine's employment has not kept pace with its population growth.

The coastal economy closely parallels that of the State as a whole. No comprehensive studies exist on the economy of the coast as a distinct region. Colgan (1979) has conducted a preliminary examination of the coastal economy using data from State agencies. The coastal economy began to decline following the Civil War, when the population growth rate declined and market demand for natural resources, such as granite, salt, ice, and some farm products, was altered by increased use of cement and refrigeration and by competition from markets elsewhere.

The railroad and the steamship contributed to the growth of tourism which became one of the most important elements of the coastal economy. Bar Harbor (region 5), Rockport (region 4), Boothbay (region 2), and Portland (region 1), all thrived as resort areas. Tourism grew rapidly after 1920, when the automobile increased access to coastal peninsulas that rail service had not reached.

The coastal economy was almost wholly built upon natural resources, which were, for the most part, renewable and plentiful. These resources include water, fisheries, wood, and minerals. The decline in Maine's industry that began after the Civil War continued until World War II. The availability of resources that were transported more easily and the decreased demand for natural resources contributed to the decline of the coastal economy. For example, in 1900 the demand for raw timber and lumber (which were exported through the coast) declined and the demand for paper products increased. When paper mills were built they were located inland, closer to the pulpwood resource. Only the St. Regis Paper Company in Bucksport remained on the coast. The shift in demand away from certain resources (e.g., granite, ice, salt, and farm products) resulted in a greater dependence on fishing, tourism, energy generation, and, to a lesser extent, manufacturing.

After World War II a trend toward trade and service and away from manufacturing began on the coast. During this period the trade industry became the largest employer and manufacturing fell to second place. Presently, the trade sector is the largest employer in the coastal zone (45,622 or 31.8%; table 2-15). Manufacturing industries now employ 25% of the employed persons in the coastal zone.

Table 2-15. Employment Figures by Source of Income in Coastal Maine in 1977[a]

Sources of income	Number employed		Percentage	
Primary	883		0.6	
AgForFish		672		0.4
Mining		131		0.1
Construction	8353		5.8	
Manufacturing	36,830		25.6	
Food		5481		3.8
Textiles/Leather		10,512		7.3
Forest products		3378		2.3
Printing		2112		1.4
Chemical/Petroleum		1322		0.9
Stone, Clay, Glass		516		0.4
Primary metals		40		0.1
Metals/Machinery		11,667		8.1
Miscellaneous		653		0.4
Transport/Utilities	6656		4.6	
Transportation		4347		3.0
Communications		830		0.5
Utilities		1935		1.3
Trade	45,622		31.8	
Wholesale		10,505		7.3
Retail		35,117		24.4
FIRE[b]	9573		6.6	
Services	34,710		24.1	
Tourism	15,055		10.4	
Six major industries	22,498		15.7	

[a] Colgan 1979.

[b] FIRE – finance, insurance, and real estate.

The forest products industry is the third largest employer. Data (table 2-15) do not include fishermen, timber workers, or farmers. However, Colgan (1979) estimates that there are 14,000 full-time fishermen in coastal Maine, which constitutes 10% of those employed. Additional data on numbers of fishermen are given in C. E. Maguire, Inc. (1978). The trade, services, and tourism industries in the coastal zone grew in terms of number of persons employed between 1973 and 1977 (Colgan 1979). The average wage for employed persons in coastal Maine was $9150 in 1977 (Colgan 1979). Unemployment in the coastal counties averaged 8.5% in 1976.

Transportation. Rail and air transport maps show existing routes and air terminals (figure 2-29). There are five airports on the coast, with air taxi services available to other smaller airports. No air service exists east of Bar Harbor.

Portland, Searsport, and Bangor are the three major marine cargo ports in coastal Maine. Five others are considered minor (see figure 2-29). During the period between 1970 and 1975, the amount of cargo handled at Maine coastal ports decreased by 7% (table 2-16)

Population. The first major settlements in Maine began along the southern coast and spread gradually northward and eastward. By 1790 most parts of the coast were sparsely settled and by 1860 the coastal towns were well established. The populations of many Maine communities began to decline by 1900 as colonization in the United States shifted westward. The overall State population continued to grow during that period (figure 2-30) but less rapidly after 1860. During the period between 1880 and 1970, Maine grew at an average annual rate (0.4%) that was less than New England (1.4%) and the U.S. as a whole (1.8%; Maine State Planning Office 1978).

Although no early coastal population data have been assembled at the county level, an approximation of trends (figure 2-32) can be made. Washington and Hancock Counties showed rapid growth from 1840 to 1860, during the boom in shipbuilding, lumber and timber, quarrying, and fishing. Their populations peaked between 1880 and 1900 and began to decline thereafter. This rise, peak, and decline is best exemplified by Washington County but probably occurred in most coastal counties at an earlier time.

Each county has begun a population increase following the decline that occurred in this century. Washington County has been the last to follow in this trend, with noticeable increases beginning there in 1970 (Bureau of Census 1970). Many coastal towns had much larger populations during the early phases of the industrial age and are now, some hundred years later, considerably smaller in population.

The Maine coast has an average population density of about 65 persons/sq mi according to 1974 data. The range of densities in each region varies from about 540 persons/sq mi in region 1 to about 35 persons/sq mi in region 6 (table 2-17). The range of coastal densities by town varies from 3400 persons/sq mi in metropolitan Portland (region 1) to 0.45 persons/sq mi in Centerville in region 6. The ten most densely populated towns in the coastal regions are listed in table 2-18.

Coastal population projections were made available by the State Planning Office (1978) for the coastal counties (table 2-19). Since these projections include the slower-growing and declining urban areas, the possible rapid growth expected in smaller coastal towns is partially obscured. Although data in table 2-19 show a projected growth rate for Hancock, Sagadahoc, and York Counties of 7% between 1977 and 1980 and 4% from 1980 to 1982, Keeley (1979) states that Hancock County is expected to grow by 8% between 1980 and 1990. Portland, however, with slower urban growth, may increase only 1% or less during this period.

According to population estimates between 1970 and 1975, the coastal counties grew 7.3%, whereas growth for the State as a whole was only 5.5% (Maine State Planning Office 1978). Recent data developed by Ploch (1976) appear to show a definite trend of "in-migration" for the coast and inland areas. This group is composed of young formerly urban residents, older retired persons, and some natives of all ages who are returning to their home towns.

Land use. The terrestrial habitat of coastal Maine is dominated by forests (86% of land area) and includes developed land (10%) and agricultural land (4%). Atlas map 2 identifies land cover in coastal Maine, but measurements of the extent of the habitat types are not available. Land use varies regionally. In region 1, 28% of the land cover sampled was developed land and 15% was residential (Cohen 1979). In regions 3 and 4, 10% of the land was developed and 5% was residential (Cobb 1979). In region 5, 15% was developed and 6% was residential (Keeley 1979). No data are available for the other regions.

A projected land-use plan for the Portland area includes the seven coastal towns in region 1. In region 1, 17% of the undeveloped land will be developed by the year 2000 (Cohen 1979). In all, 43% of the land will be developed in coastal towns in this region by that year.

Fresh water supply. The recent survey report on water supply in the coastal zone (Caswell and Ludwig 1977) examines conditions in each coastal town, describes water supply and quality problems, and projects further demand. Demand is based on population growth, building starts, and increases in numbers of commercial-industrial water users. Sources of potable water exist throughout the coastal zone, often within town limits. Deterioration of water quality due to artificial contamination is probably the single greatest water supply problem in the coastal zone. The presence of algae, color, turbidity, and coliform bacteria are typical indicators of this contamination. Salt water intrusion, road salt, heavy metals, and petroleum products have seriously affected local drinking supplies. Regional areas cited as problem areas are Boothbay-Bristol, Western Penobscot-Belfast, and Milbridge. These areas may be forced to turn to inland sources in the future.

Socioeconomic research needs. Much socioeconomic data on Maine are available, but its form is not useful in evaluating the socioeconomic status of coastal Maine as a distinct area. Many data categories (i.e., income, value of products, employment, resource amount and value) are available only at County aggregate levels, not at town or municipal levels.

Data were unavailable or aggregated at unusable levels for many resource categories of which the following are examples:

1. Forestry: reporting areas too large, data old, hard to separate coastal from inland data
2. Firewood use, value, and demand expectations
3. Gravel and sand: location, value, amount
4. Agricultural: coastal crops, value, accurate amounts (acreage) of productive crop land
5. Fisheries: sport fish (salt water, migratory, and estuarine), finfish values by area caught and landed
6. Wildlife: accurate trap-tag data by species and town
7. Fresh water: fresh groundwater amounts for coastal areas.

All data based on the population census of 1970 are estimates and in some cases are thought to be in error. This is especially true in Washington County, where the 1970 census showed gains in the populations of nearly all the towns after 70 years of losses. Information on net migration and the growth of the coastal towns by in-migration is lacking and is of major importance.

With the exception of Washington County, existing land-use data appear to be available for the coastal zone, although the data are not comparable from region to region. Projections for future demand of various uses and the pattern or trend of these developments are lacking for regions 2 to 6.

No data are available on the numbers of people using recreation facilities or the amount of money spent at nonsupervised, private or quasi public facilities. Similar data are lacking for recreational boating and fishing.

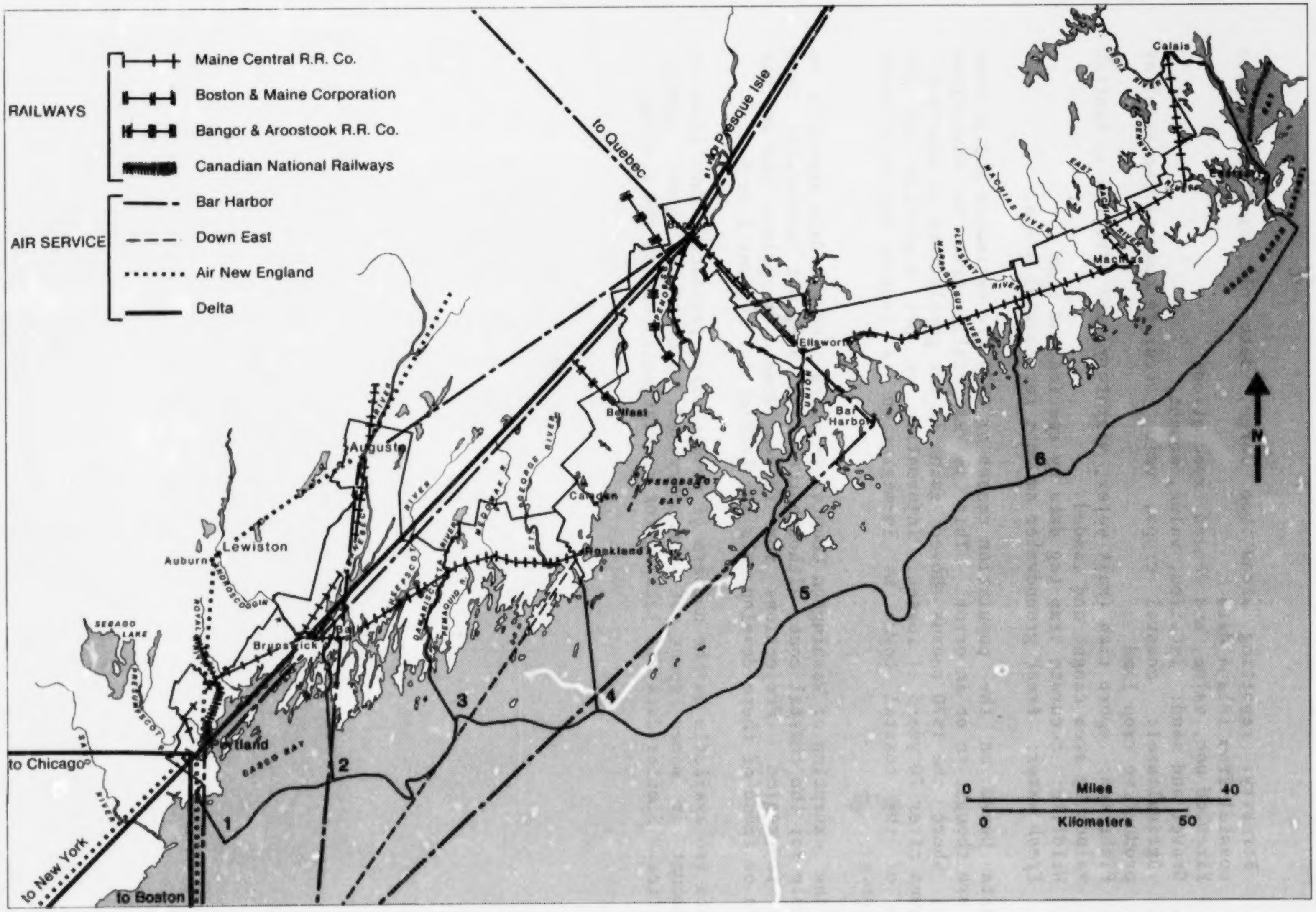
RAILWAYS
Maine Central R.R. Co.
Boston & Maine Corporation
Bangor & Aroostook R.R. Co.
Canadian National Railways
AIR SERVICE
Bar Harbor
Down East
Air New England
Delta
to Quebec
to Presque Isle
to Chicago
to New York
to Boston
Portland
CASCO BAY
SEBAGO LAKE
Auburn
Lewiston
Brunswick
Bath
Augusta
Rockland
Camden
Belfast
PENOBSCOT BAY
Ellsworth
Bar Harbor
Machias
Calais
Eastport
1
2
3
4
5
6
N
0
Miles
40
0
Kilometers
50

Figure 2-29. Railways and commercial air service in coastal Maine (Maine State Planning Office 1978).

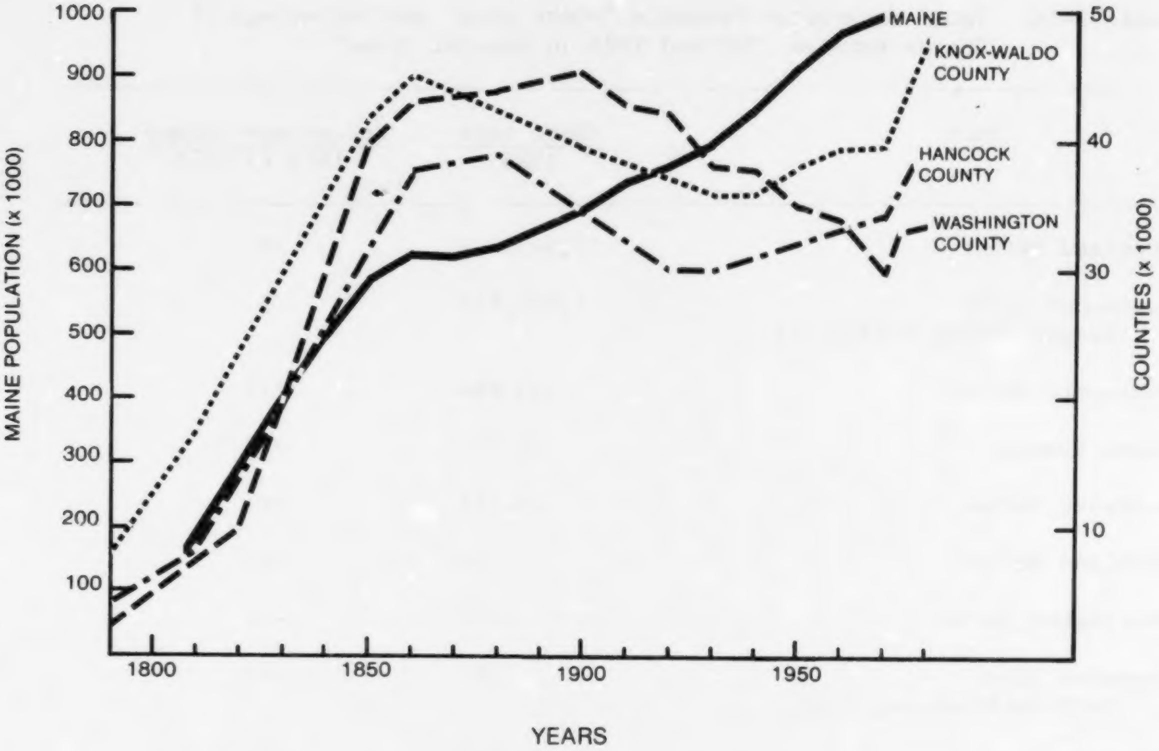

Figure 2-30. Population trends in Maine and in several coastal counties between 1790 and 1980 (1980 estimated; Bureau of Census 1970; and Maine State Planning Office 1978).

Table 2-16. Total Waterborne Commerce (short tons) and Percentage of Change Between 1970 and 1975 in Coastal Maine[a]

Port	Short tons 1975	Percentage change 1970 to 1975
Portland Harbor	27,565,807	-8
Penobscot River (Bangor-Brewer-Bucksport)	1,667,833	-7
Searsport Harbor	1,365,860	+35
Lubec Channel	38,083	+38
Eastport Harbor	19,721	+9
Rockland Harbor	17,760	-41
Stonington Harbor	4863	-46
Kennebec River (Bath-Gardiner-Augusta)	1985	-40
All others	29,899	-49
Total	30,694,051	-7

[a] Maine Department of Transportation 1977.

Table 2-17. Population Density (persons/sq mi) and Total Population Size (sq mi) in Maine Regions in 1974[a]

Region	Size (sq mi)	Population	Density/sq mi
Region 1	240	130,000	540
Region 2	455	72,000	160
Region 3	310	18,200	60
Region 4	735	91,200	115
Region 5	605	25,000	40
Region 6	580	21,000	35

[a] Maine State Planning Office 1978.

Table 2-18. Population Density in Major Towns and Cities of Coastal Maine in 1974[a].

City	Size (sq mi)	Population	Persons/sq mi
Portland	19	65,000	3400
South Portland	13	23,000	1700
Bath	10	9990	1000
Bangor	35	33,000	950
Randolph	2	2000	940
Rockland	13	8800	680
Brewer	15	9300	615
Cape Elizabeth	15	8000	570
Eastport	5	2200	480
Hallowell	6	2700	470

[a] Maine State Planning Office 1978.

Table 2-19. Projected Population Sizes for the Coastal Counties in 1977, 1980, and 1982 and Percentage of Population Gain[a]

County	No. of persons	No. of persons	% pop. gain	No. of persons	% pop. gain
	1977	1980		1982	
Cumberland	205,700	211,000	3	213,700	.1
Hancock	40,700	43,500	7	45,300	4
Kennebec	103,200	106,500	3	108,200	0.1
Knox	33,300	35,200	6	36,400	3
Lincoln	23,900	25,400	6	26,300	3
Sagadahoc	27,300	29,100	7	30,200	4
Waldo	27,400	29,300	7	30,400	4
Washington	33,600	35,200	5	36,200	3
York	126,000	132,300	5	136,200	3
Total	621,100	647,500	4	662,900	2
State total	1,080,900	1,117,100	2	1,137,200	1

[a] Maine State Planning Office (1978).

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Chapter 3
Human Impacts on the Ecosystem

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Natural processes in the coastal zone interact with human activities, such as (1) waste generation:release of solid, liquid and atmospheric waste into the system; (2) habitat modification:forest harvest and burning, and wetland impoundment, draining, and filling; and (3) natural resource exploitation: harvest of fish, wildlife, and vegetation. These alterations of the ecosystem set off complex and often detrimental environmental reactions. For example, alterations of surface water flow by people, trigger chain reactions that affect water supply, water quality, and fish and wildlife populations and habitats. Some key interactions are highlighted in table 3-1. Additional and more specific information can be found throughout the characterization, including the atlas. For example, impacts on a species or group of species, such as waterbirds, fish, or terrestrial mammals, are enlarged upon in chapters 14, 11, and 17 respectively.

Most human impacts on the Maine coast are localized (e.g., contamination of shellfish beds and modification of habitats by dams, roads, and other facilities). However, the effects of some human activities are widespread and are difficult both to measure (e.g., acid rain and cumulative impacts) and to control. These may threaten the ecosystem in the future.

The purpose of this chapter is to alert the reader to potential environmental problems on the Maine coast. It describes these problems and, in some cases, suggest options for their solution, so that the integrity of the coastal ecosystem can be maintained or improved by informed decisions in coastal management.

State and Federal regulations are in effect to control or offset the adverse environmental impacts of human activities. A summary of these regulations and their enforcement is included at the end of this chapter.

For the most part, data on the threats to the coastal habitats of Maine are based on findings or reports from other coastal states, since such data on Maine are unavailable.

Table 3-1. Socioeconomic Activities in Coastal Maine and Their Ecological Interactions[a]

Activity	Interaction										
	Waste generation		Habitat modification						Natural resource exploitation		
	Point source dis-charges	Upland runoff	Impound-ment	Filling and drain-ing	Upland con-struction	Dredging and fill disposal	Harvest of vegetation	Distur-bance	Fish and wildlife harvest	Water use	Refuge, park creation, and maintenance
Fishery	X		X	X		X			X		
Forestry	X	X		X	X		X	X	X		
Agriculture		X	X	X	X		X	X		X	
Mineral extraction	X		X		X		X	X		X	
Port and navigation	X	X		X		X				X	
Transportation		X	X	X	X	X	X	X			
Tourism and recreation	X				X		X	X		X	X
Sport fishing and hunting			X					X	X		X
Industry and population	X	X	X	X	X	X	X			X	

[a]Adapted from Gosselink et al. 1979.

COMMERCIAL FISHERIES

Excepting local harvest of eels and alewives in the riverine system, commercial fishing in coastal Maine occurs only in the estuarine and marine systems. Harvesting and processing of finfish and shellfish cause local and regional ecological problems, through waste generation (from boats and processing plants), habitat modification (piers, dockside facilities, and processing plants), and reduction of populations.

Processing fish produces waste that may contaminate local intertidal flats and the water column. Thirty-four fish-processing plants in coastal Maine possess waste water discharge permits (regulated by Maine Department of Environmental Protection as of March, 1979; see atlas map 3). The impacts of water pollution are discussed below under "Population and Industry."

Commercial fish harvest, particularly the mechanized harvesting of scallops and mussels, worm and clam digging, and lobster impounding, modifies the marine and estuarine habitats and populations. Mechanized scallop harvesting equipment traps and crushes benthic invertebrates in the trawls used to drag for scallops. Drags also resuspend bottom sediments and nutrients, which increases water turbidity, and results in (1) reduced light penetration, (2) the smothering of benthic invertebrates, and, occasionally, (3) excessive nutrient enrichment of surface waters. Worm and clam digging disrupt intertidal flats and expose invertebrates to dessication, freezing, predation, and physical damage. These effects may be most severe in winter when many invertebrates burrow to deeper depths to escape the harsh surface conditions. Impoundments for the storage of lobsters may (1) result in the loss of intertidal habitats, (2) obstruct fish passage, and (3) alter sedimentation patterns.

Commercial fish harvest may disturb seal breeding areas, seabird breeding sites, and bald eagle nesting sites. "Marine Mammals," chapter 13, "Waterbirds," chapter 14, and "Terrestrial Birds," chapter 16, discuss the effects of human disturbance of breeding locations on reproductive success.

Fish weirs and stop seines may trap marine mammals (especially whales; see chapter 13, "Marine Mammals"). Fish seines also may entrap and drown diving seabirds. (No data are available on this problem in Maine but it has been documented elsewhere.)

Fish piers, breakwaters, boat launches, and docks constructed by the fishing industry have ecological impacts. These are discussed below under "Port and Navigation." Certain harbors that are important in commercial fishing (e.g., Alley's Bay in region 6) are maintained through dredging operations, that have adverse ecological effects (see "Port and Navigation" below, and atlas map 3).

Stocks of shrimp, haddock, sturgeon, and other fishes, are currently low in comparison to historic numbers. Declines in abundance are often unnoticeable statistically (e.g., through catch trend analysis) until the decline has reached an advanced stage. Intensified fishing efforts and utilization of more selective equipment tend to counterbalance catch shortages temporarily.

FORESTRY

The forest industry harvests and manages forests and processes wood products. These activities generate waste (e.g., slash on site and effluents from processing plants) and modify habitats (e.g., clear cutting and use of herbicides). The forest industry primarily affects the terrestrial, lacustrine, palustrine, and riverine systems; although the estuarine system is affected locally by waste products from paper mills and wood products industries (i.e., mills along the Presumpscot, St. Croix, and Penobscot Rivers) and by receiving wastes that originate upstream.

Harvesting practices employed in Maine are discussed in chapter 19, "Commercially Important Trees." Two major methods are employed: uneven-aged management and clearcutting. Uneven-aged management employs a selective harvest system, removing only selected, mature trees that normally would be lost through natural mortality. This harvest system is best for regenerating shade-tolerant tree species, because it maintains a closed canopy at all times. Selective harvest usually does little damage to forest systems. Some disturbance of the forest floor and understory vegetation by machinery and road construction does take place, however. These disturbances could affect threatened and rare forest plants (see chapter 20, "Endangered, Threatened, and Rare Plants"). Opening the forest canopy may affect songbird density and the species composition of wildlife (see chapters 16 to 18). Streams and palustrine wetlands may be affected adversely by road construction, which increases siltation and alters drainage patterns.

Clearcutting severely alters water and nutrient cycles, interrupting patterns of productivity, biomass accumulation, decomposition, and mineralization. Removal of the forest canopy increases solar radiation, raising soil and water temperatures. Removal of trees curtails transpiration, thereby reducing the rate at which water is removed from the soil and temporarily raising the water table. Higher soil temperature and moisture levels promote accelerated nitrification and decomposition of litter, which releases more nutrients into the available nutrient pool. The forest vegetation no longer participates in the flow of water through the systems, resulting in increased losses of water to streamflow and higher peak runoff during storms. Increased runoff aggravates the erodibility of the forest floor, which increases particulate matter and nutrient loss in the local ecosystem. A detailed discussion of the effects of wood harvesting on the nutrient cycle of a forest in New Hampshire can be found in chapter 9, "The Forest System." Quantitative data on Maine's forests are unavailable, but the results of the New Hampshire study are generally applicable to coastal Maine.

The extent to which forest systems are affected by harvesting depends on the care with which logging is carried out. Excessive disturbance of the forest floor and residual understory vegetation by heavy machinery exposes the soil to erosion and thereby delays forest regeneration. Threatened and rare forest plants can be affected severely by clearcutting, especially if site-preparation techniques are employed (i.e., bulldozing, burning, or use of herbicides). Improperly placed roads can stimulate excessive (and avoidable) erosion and cause soil compaction. Cutting too close to streams may cause erosion of banks and exposes stream surfaces to the sun, which increases water temperature. Significant changes in species composition (e.g., fish and insects) in streams as a result of forest clearcutting and agricultural activities have been documented in New Brunswick (Welch et al. 1977). Areas that have been clearcut may be distant from a seed source needed for regeneration (which is usually the case in Maine's spruce-fir stands; Frank and Safford 1974). Cutting on steep slopes with shallow soils may lead to erosion and delayed regeneration. The watershed approach to cutting patterns, which allows only a certain portion of a watershed to be harvested at any one time, is a wise method of management that can prevent serious downstream impacts.

Negative effects of clearcutting practices on the lacustrine, palustrine, and riverine systems include siltation, excessive nutrient enrichment, and changes in water levels and/or water flow. The impacts of soil erosion, siltation, and nutrient enrichment on coastal flora and fauna are discussed further below under "Agriculture," "Water Pollution," and "Dredging."

Palustrine wetlands and small streams may be affected by the construction of hauling roads and skid trails, which may alter surface runoff patterns. During winter, skid trails of small logging operations often pass over open and frozen bogs and emergent wetlands.

Skidding logs across streambeds, sphagnum bogs, and other wetlands disturbs bottom sediments, which may result in downstream siltation. Cutting vegetation immediately adjacent to streams has a similar effect. Skid trails also disturb natural drainage patterns, altering stream flow and silt load. Abandoned skid trails may continue to alter stream flows indefinitely if they are not properly modified (e.g., cross-ditched) after active logging ceases. Haul roads used to move wood to mills pose problems of drainage disturbance and siltation similar to those caused by skid trails.

Maine rivers are affected adversely by bark and woody debris (from rafted logs during historical log drives) that often cover the bottom and reduce populations of invertebrates (important fish food) at least temporarily (Smith 1978; and Bond and DeRoche 1950). Decomposition of this material reduces dissolved oxygen levels in bottom waters. Log debris also may block spawning sites, interfering with trout and salmon reproduction. Under certain conditions, log substrates provide fish cover and additional attachment sites for invertebrates. This litter persists in streams where colder temperatures (and faster moving water) slow decomposition. For example, the river bottom and adjacent palustrine emergent wetlands along the East Machias River (region 6) are covered with undecayed logs, sawdust, and wood debris from saw mills that were last active during the 1940s.

The removal of forests from coastal islands may affect eagles, ospreys, and waterbirds that nest in trees (e.g., herons) or under trees (e.g., Leach's storm petrels). Waterbirds nesting in open areas of forested islands may be affected by the presence of wood cutters, tree-removal activities, and noise during the breeding season. The effects of tree removal on eagles are discussed further in chapter 14, "Terrestrial Birds," and its effects on waterbirds are discussed in chapter 16, "Waterbirds." Culling of dead and diseased trees may affect cavity-nesting species of waterfowl, terrestrial birds, and mammals (see chapters 15, 16, and 17, "Waterfowl," "Terrestrial Birds," and "Terrestrial Mammals," respectively).

Although growth exceeds removal of total growing stock, the growth-to-removal ratios of merchantable northern white cedar, northern red oak, white ash, yellow birch, white pine, sugar maple, and beech show over cutting. These trends can be expected to continue because of the increased demand for firewood. Projections of future timber supply show that if present removal trends continue hardwood removals will exceed merchantable growth within 10 years, and softwood removals will exceed merchantable growth before the turn of the century.

Old, mature trees are valuable to the forest system. The Maine State Planning Office is currently evaluating existing stands of mature forests for consideration as critical areas. Preserving mature forests helps perpetuate an entire community of herbaceous species that do not tolerate repeated disturbances, such as lumbering. Although trees are renewable natural resources, replacement of very old trees requires many years, especially under the conditions created by the short rotation (harvest) cycles currently employed by the forest industry.

Clearcutting often results in the fragmentation of forests. The effects of forest fragmentation on wildlife are not known fully. However, studies of songbirds and mammals have shown that as the size of undisturbed habitats (e.g., forests) decreases (1) the number of species dependent on those habitats decreases, and (2) the number of species using only small areas of those habitats decreases, also. For example, certain songbirds that inhabit forest interiors in New Jersey and Maryland are not found in woodlots smaller than 20 acres (8 ha), even though they may utilize only a few acres. This relationship between species abundance and size of continuous habitat follows island biogeography theory, which predicts that the number of species will decrease as island size decreases or as distance from the mainland (major population pool) increases. In terrestrial habitats on islands, large blocks of continuous natural vegetation are analogous to the mainland.

Other practices associated with logging or regenerating the forest stands also may affect the system. These include the spraying of herbicides and pesticides and the piling and burning of slash. Herbicides are used in the management of softwood (e.g., spruce-fir) to kill deciduous trees, shrubs, and herbaceous plants (e.g., raspberry, cherry, birch, and aspen) that often dominate clearcut sites for many years. These species prevail over the commercially desirable softwood species at early seral stages in much of Maine's forest land, and their dominance delays forest crop rotation. Herbicides similarly affect endangered, threatened, and rare plant species. Selective herbicides are used to kill these "weed" species when adequate softwood regeneration is present or prior to planting softwood seedlings. The long-term effect of removing these plants from regenerating forests is not known. The effect of herbicides on the terrestrial system is discussed further in chapter 9, "The Forest System."

Herbicides (through direct application and runoff) can affect riverine, palustrine, and lacustrine systems by killing aquatic vegetation, changing local aquatic habitats, and depleting oxygen (through the decomposition of the dead material). Very high doses of herbicides can kill fish. The effects of the relatively low amounts that are used currently by the forest industry are unknown but do not produce observable effects.

The pesticides currently used in forest systems to control insect defoliators (primarily the spruce budworm), include Carbaryl or Sevine[1], Orthene, and Dylox. These are short-lived and break down rapidly. Consequently, they do not accumulate to toxic levels within food chains, as did some of the persistent pesticides used in the past. DDT, a persistent pesticide, was used in spruce budworm control in Maine from 1954 to 1967. Dylox is used primarily near blueberry barrens along the coast, because of its low toxicity to bumblebees, which pollinate blueberries. Orthene is used near lakes, ponds, and rivers. Sevin has been used most extensively outside the coastal zone. When used correctly at current concentration levels, these pesticides pose little threat to the environment. The difficulties that do arise concerning them are usually due to inadvertent overdosing, which results from drift and/or imprecise positioning of aircraft during application.

No direct mortality among fish and birds has been reported for the above chemicals at current spray levels in coastal Maine (Dube 1977). However, significant deviations in acetylcholin-esterase activity (an indicator of nervous system functioning) have been documented in salmonids, creek chubs, and suckers that have been subjected to Matacil, Sevin, Dylox, and Sumithion respectively (Rabeni 1978). Nontarget insects may be killed by the spray, and species that utilize insects as food, such as most birds, mammals, fish, amphibians, and reptiles may be affected in this way. Reductions in standing crops of invertebrates in Maine streams have been found after spraying with DDT (Dimond 1967), Sumithion (Rabeni and Gibbs 1976), and Sevin (Courtemanch and Gibbs 1977). Orthene and Sumithion also have been shown to affect invertebrates by increasing drift (downstream displacement), without causing a detectable decrease in standing crop. Although these chemicals may not be acutely toxic the effects of long-term exposure on reproduction and behavior are unknown. The acute and chronic effects of forest spraying on songbirds are discussed, in chapter 16, "Terrestrial Birds." The impact of pesticides is also discussed below under "Agricultural Impacts."

The larger paper mills and, to a lesser extent, sawmills and wood products industries are sources of air pollution and water pollution. Licenses are required for operating these facilities and they are monitored by the Maine Department of Environmental Protection (DEP). The major water quality problems associated with these operations are the discharge of heavy metals (e.g., lead and copper) and organic materials. The effects of their waste water effluent are described below under "Industry and Populations."

AGRICULTURE

Agricultural lands (croplands, pasture lands, and blueberry barrens) comprise about 4% of the coastal zone. An additional 2% consists of abandoned agricultural lands. Soil erosion and runoff from manure, fertilizers, and pesticides sometimes pose ecological problems. According to paleolimnological studies (Davis and Norton 1978), agriculture has greater effects on lakes in New England than any other activity. Agricultural activities take place in areas that were formerly forests, barrens, or wetlands.

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[1] Use of trade name does not imply government endorsement.

Soil Erosion

High surface runoff from cleared agricultural land causes excessive erosion of soil. Between 2000 and 7350 tons (1815 and 6670 t) of soil are eroded away annually in each region of coastal Maine (U.S. Soil Conservation Service 1979). The most important factors causing soil erosion in Maine have been identified as steepness and length of slope, poor rotation cycle, and uphill/downhill cultivation (U.S. Soil Conservation 1979). Soil-type is another contributing factor. Tolerable soil loss for Maine's soil, as established by the Soil Conservation Service, is 3 tons (2.7 t)/acre/year. Locally severe soil erosion problems are, however, possible at lower levels than this. Knox and Lincoln Counties (regions 3 and 4) have the highest average soil loss (12.8 tons; 12 t/acre/year). Waldo County (region 4) follows with 5.6 tons (5 t)/acre/year. Sagadahoc County (region 2) has an average soil loss of 2.4 tons (2.1 t)/acre/year which is below tolerable levels. Approximately half of the 2900 acres (810 ha) of cropland surveyed for soil loss in the characterization area were above tolerable levels.

Eroded soil is deposited in streams, lakes, ponds, upland fields, and flood plains. Two bodies of water in region 1 were found to receive approximately 30% of the total sediment that is in motion in their respective watersheds during the year. Sediment carries pesticides and nutrients and excessive sediment reduces water quality.

Excessive sediment deposits and turbidity can reduce the capacity of a pond or stream to produce fish and other desirable aquatic organisms. Fish habitat can be destroyed and juvenile fish can be killed by silt-laden water. Fine sediment may clog the gills of finfish and other aquatic organisms. Turbid water may affect the productivity of aquatic plants by reducing light penetration. Silt deposits on the leaves of submerged aquatics have a similar effect. Reducing the aquatic invertebrate species and aquatic vegetation limits the primary foods and important cover of juvenile salmon, trout, and bass. Over long periods of time fish become fewer and smaller.

Nutrient Runoff

Excessive runoff from animal manure and fertilizer pollutes the waters of coastal Maine (U. S. Soil Conservation Service 1979). The most widespread pollution of this kind in Maine is caused by improper storage of manure.

No specific data are available on the amount of manure spread on fields or the number of improper storage facilities in the characterization area. Waldo County (regions 3 and 4) has the highest number of animal units (30,100) and, consequently, the highest production of manure (350,000 tons; 372 t/year). [An animal unit is a standardized measure of livestock biomass and is equivalent to 1000 lb (400 kg), live weight.] Following in decreasing order of production are Cumberland (9250 AU in region 1), Knox and Lincoln (combined 5260 AU in regions 3 and 4), Sagadahoc (2010 AU in region 2), Hancock (1583 Au in regions 4 and 5), and Washington (1325 AU in regions 5 and 6) Counties. The greatest number of large farms (>1000 AU) is located in the Androscoggin and Kennebec watersheds. Most are within 30 miles of the coastal zone. A large number of farms >500 AU are located along the Penobscot River and its tributaries.

The transport of agricultural fertilizer takes place by means of surface runoff, spraying, soil erosion, and leaching. Most chemical fertilizers are soluble and large quantities may be carried away by surface runoff. Since the scarcity of phosphorus may limit plant growth in freshwater systems, additions of phosphorus may accelerate growth. The scarcity of nitrogen limits plant growth in estuarine systems.

Excessive nutrient runoff degrades water quality in the lacustrine, palustrine, riverine and terrestrial systems, and in poorly-flushed portions of estuaries and embayments. In most estuaries flushing is adequate to disperse and dilute agricultural runoff.

The concentrations of animal-related nutrients actually reaching ground and surface waters are difficult to determine. A study in Kennebec County (immediately north of the characterization area) indicated that about 10% of the animal-related phosphorus there reached lakes in that watershed, approximately 1.4 lb (0.6 kg)/acre/year.

Fertilizer runoff into lakes, ponds, and even wells can cause public health problems. Livestock and aquatic life also can be affected when large amounts of fresh manure accumulate in water. Bacteria, viruses, protozoans, and fungi are among the pathogens found in manure. Enrichment of lakes and ponds can result in excessive growth of algae, which may cause taste, odor, and discoloration in water and its recreational value (e.g., Pleasant Pond, region 2). Excessive algal growth accelerates the eutrophication process. The decay of the excess plant material by microbes depletes dissolved oxygen supplies to levels that are lethal to fish. In addition, oxygen-depleted water may cause mortality of some aquatic insects. High levels of nitrate in groundwater used for water supply can cause methemoglobinemia, a rare blood disorder in infants (U.S. Soil Conservation Service 1979).

Pesticides

A wide variety of agricultural chemicals are now used within the characterization area (table 3-2). Although little field research has been conducted on the toxicity of agricultural pesticides in Maine, isolated instances of pesticide damage to the environment have been observed. The amounts of agricultural chemicals used within certain coastal watersheds are shown in table 3-3. In comparison to other parts of the country, pesticide use in Maine could be considered moderate to low (personal communication from A. Julin, U.S. Fish and Wildlife Service, Newton Corner, MA; February, 1980).

Agricultural pesticides are used mostly on corn and other vegetables, fruit, hay and other forage crops in all regions except 5 and 6, where most spraying is on blueberries. Approximately one-half of the 15,000 acres (6073 ha) of blueberry barrens in regions 5 and 6 have been sprayed with Guthion . This insecticide caused a fish kill at a fish hatchery in Deblois (Washington County) in 1972; 10,000 brook trout and 11,000 eggs were destroyed through careless aerial spraying. Fish kills have occurred in the past due to DDT in the Pleasant (regions 5 and 6) and Narraguagus (region 5) Rivers.

Table 3-2. Pesticides Registered for Use in Maine and the Crops for Which They Are Used[a]

Crop	Herbicides		Insecticides		Fungicides	
	Trade name[b] or commonly used Generic name		Trade name	Generic name	Trade name	Generic name
Corn	Atrazine		Furadan	carbofuran		
	Lasso	alachlor	Sevin	carbaryl		
	Bladex	cyanazine	Malathion	malathion		
	Roundup					
	Banvel	diacamba				
	Paraquat	paraquat				
Fruit			Acaralate		Benlate	benomyl
			Carzol		Captan	
			Cygon	dymethoate	Cyprex	dodine
			Delnav	dioxathion	Difolatan	dicaptafol
			Dimecron	phosphamidon	Dikar	
			Di-Syston	disulfoton	Fermate	ferbam
			Ethion		Manzate D	maneb
			Guthion	azinophos-methyl	Niacide M	
			Imidan	phosmet	Phaltan	folpet
			Kelthane	dicofol	Phygon	dichlone
			Malathion		Polyram	metiram
			Omite	propargite	Sulfur	
			Plictran	cyhexatin	Thylate	thiram
			Sevin	carbaryl	Zineb	
			Systox	demeton		
			Tedion	tetradifon		
			Thiodan	endosulfan		
			Vendex			
			Zolone	phosalone		
Vegetables	Atrazine		Sevin	carbaryl	Manzate D	maneb
	Premerge	dinoseb	Malathion		Benlate	benomyl
	Bladex	cyanazine	Methoxyclor		Dithane M-45	mancozeb
	Dow general mixture		Guthion			
			Systox VI	demeton		
			Disyston 15G	disulfoton		
			Monitor	methamidophos		
Forage Crops	Eptam 7E					
	Balan					
	Tolban 4E					
	Butyrac 200					
	Butoxone					
	Premerge	dinoseb				
	Sinox PE	DNOC				
	Furloe	chloropham				
	Princep	Simazine				
	Kerb	pronamide				
	2,4-D					
Blueberries			Diazinon			
			Guthion			

[a] U.S. Conservation Service 1979.

[b] Use of trade name does not imply Government endorsement.

Table 3-3. Amount (pounds unless stated otherwise) of Pesticides Applied to Crop Land in Five Watersheds in the Characterization Area[a].

County/ Watershed	Crop	Chemical	Amount per acre	Acres	Total[b]
Knox (Region 4)					
St. George River	Corn	Atrazine	2.5	100	250
		Bladex	2.5		250
		Lasso	4 qts		400 qts
	Blue-berries	Diazinon 4%	25	600	15,000
		Ferbam 7.6%	15		9000
		Sevin 5%	20		12,000
Megunticook River	Corn	Atrazine	2.5	78	195
		Bladex	2.5		195
		Lasso	4 qts		312
	Blue-berries	Diazinon 4%	25	256	6400
		Ferbam 7.6%	15		3840
		Sevin 5%	20		5120
Lincoln (Regions 2 and 3)					
Medomak River	Corn	Atrazine	2.5	200	500
		Bladex	2.5		500
		Lasso	4 qts		800 qts
	Blue-berries	Diazinon 4%	25	400	10,000
		Ferbam 7.6%	15		6000
		Sevin 5%	20		8000
Damariscotta River	Corn	Atrazine	2.5	120	300
		Bladex	2.5		300
		Lasso	4 qts		480 qts
	Blue-berries	Diazinon 4%	25	175	4375
		Ferbam	15		2625
		Sevin 5%	20		3500
Sheepscot River	Corn	Atrazine	2.5	69	173
		Bladex	2.5		173
		Lasso	4 qts		276 qts
	Blue-berries	Diazinon 4%	25	69	1725
		Ferbam 7.6%	15		1035
		Sevin 5%	20		1380

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[a] U. S. Soil Conservation Service 1979.

In contrast to fertilizers, pesticides are usually insoluble in water and reach waterways or groundwater by erosion, sedimentation, leaching through soil, or by spilling. They degrade water quality and can be toxic to aquatic organisms. The movement of pesticides on cropland is generally horizontal rather than downward through the soil profile. Thus, the greatest threat of pesticides is to surface water, although groundwater can be affected also. An extended period of precipitation is needed to move pesticides deep into soil, and it is unusual to find pesticides in the soil below 2 feet (0.6 m). Local groundwater contamination may result from improper disposal of pesticide containers. Pesticides from containers buried in landfills sometimes seep into groundwater.

A study on nonpoint agricultural pollution (U.S. Soil Conservation Service 1979) identified the watersheds of the Pleasant, Narraguagus, and Harrington Rivers as susceptible to contamination by chemical pollutants. These rivers drain the blueberry barrens in the southeast corner of Washington County (regions 5 and 6). Schoodic Lake, a shallow spring-fed kettlehole lake in the middle of the barrens, is vulnerable to any contamination that may occur within its drainage area.

Little is known of the amounts of pesticides and defoliators that reach water bodies in coastal Maine. Borns and coworkers (1971) showed that pesticide levels in the groundwater supply in the Cherryfield area (region 5) after the blueberry fields had been treated often have approached the maximum limits for human consumption. Pesticides readily enter the groundwater supply through the porous glacial till. This condition is most serious when heavy rains follow pesticide applications.

During the last 10 years, a change has taken place from long-lasting hydrocarbon pesticides (organochlorines) to more toxic but shorter-lived pesticides (carbamates and organophosphates) that are known to have fewer residual effects. This change, together with improved pesticide management practices, has resulted in fewer fish kills. The latter fact may indicate that direct environmental effects are being reduced.

The most visible result of pesticide contamination is fish and songbird mortality. Fish kills are often the result of high concentrations of chemicals entering a water body within a short period of time. They also can occur after a rainfall that has been preceded by pesticide application, or when chemicals are spilled or are sprayed into water accidentally. Songbird dieoffs occur when pesticides with high bird toxicity are applied, particularly when they are applied aerially. Examples are diazinon, fenthion, carbofuran, and parathion.

Pesticides also may have a more subtle effect on aquatic ecosystems if present at low levels for long periods of time or if frequent contamination occurs. Fish behavior and reproduction may be affected by chronic toxicity. The behavior and reproduction of insectivorous songbirds (95% or more of coastal Maine breeding birds) may be affected by chronic toxicity and by severe decreases in insect populations. Canopy-feeding species are generally the most vulnerable. The effects of pesticides on songbirds are discussed in chapter 16, "Terrestrial Birds." Biological magnification may occur with some persistent pesticides, such as organochlorines, which degrade at a slow rate and become concentrated in the tissues of organisms high in the food chain.

The effects of persistent pesticides used in the past on forests and farms are still present in Maine. Although only traces or undetectable amounts of these chemicals are now found in natural waters, chemicals applied from 1954 to 1967 still are concentrated in the food chain. A major example is the harmful amounts of organochlorine chemicals still being found in bald eagles and in their eggs. Reproduction of bald eagles has been limited seriously by persistent pesticides (DDT and its degradation products) that are no longer in use. The effects of pesticides on bald eagles are discussed in chapter 16, "Terrestrial Birds."

Most of today's pesticides are short-lived compared to chlorinated hydrocarbons (i.e., DDT) but they are still extremely toxic. The potential for damage to wildlife exists largely at the time of application.

Habitat Modification

Land-clearing modifies habitats to a greater degree than any other human activity. Most of the land currently in agriculture has been farmed for many years. The oldest farm sites were developed primarily in upland areas, where the forests were cleared first. Abandoned agricultural land in Maine reverts to oldfields and eventually to forest. However, suburban expansion has taken over agricultural land in many of the more populated areas of the coastal zone (regions 1 to 5).

MINERAL EXTRACTION

The materials currently being extracted from coastal Maine are sand and gravel, peat (regions 5 and 6), limestone (region 3), and granite (region 6; see atlas map 3). Abandoned copper mines in the Blue Hill area (region 4) and granite quarries along the coast (primarily regions 4 and 5) continue to influence the local environment. Potential exists for future mining in coastal Maine. Nickel may be mined and the extraction of sand, gravel, and peat may be expanded in Knox County (region 4). Environmental impacts associated with mining include the generation of waste materials (air and water pollution) and the alteration of habitats.

Sand and gravel are extracted primarily from eskers (long sand or gravel ridges deposited in the bed of subglacial streams), which are especially numerous and well developed in Maine in comparison to other parts of the United States. Eskers are unique features of high scientific interest. They are valuable to geologists in interpreting glacial events. No estimates are available of the total length of eskers in the coastal zone. However, there are 1420 miles (2272 km) of eskers in Maine as a whole or about 0.8 cu mi ($3.3 km^3$) in volume (Borns 1979). A relatively large number of Maine eskers have been totally or partially removed for construction purposes and the rate of removal has greatly increased in the last 15 years (Borns 1979). For example, about 45% of the 37 miles (60 km) of eskers in the area encompassed by the Bangor 15-minute quadrangle map has been extracted since 1955. These trends are as high or higher in the Portland and Augusta areas (Borns 1979). Commercial exploitation of eskers is the greatest threat to their continued existence. The Maine State Planning Office is currently evaluating eskers of high scientific and educational value for designation as critical areas (Borns 1979).

Peat mining occurs in the eastern coastal areas of Maine (regions 5 and 6). Potential peat reserves that have been inventoried in coastal Maine are shown in atlas map 3. Peat reserves in some basins can be exhausted relatively quickly and recovery of the bog may require 5000 to 10,000 years. Peat mining may alter the quality of the water in bogs. Increased siltation and lowered pH caused by bog runoff can affect the ecology of downstream waters. Fish reproduction can be adversely affected by lowered pH, and siltation can smother stream invertebrates, destroy spawning sites, and alter the aquatic insect community on which fish and waterfowl feed. Smaller, poorly flushed estuaries can be affected by siltation problems, as many harvestable peat bogs are within 1 mile (1.6 km) of the coast. Snare Creek (Jonesport, region 6) drains a large bog that is currently being mined . The exploitation of raised bogs represents the loss of a unique coastal ecosystem. In the United States, raised plateau bogs are found only in northeastern coastal Maine (regions 4, 5, and 6). These bogs have a unique morphology (plateau-shaped; Damman 1977) and support a unique community of bog plants. In addition, several associations of rare plant species are found in these bogs. (See chapter 20, "Endangered, Threatened, and Rare Plants").

Hard-rock mining for limestone, granite, and mineral ores usually produces large amounts of waste water and waste rock (tailings). Ponds are constructed in mining areas to receive water pumped from the mine. These ponds usually are of limited value as wildlife habitat because of their harmful water chemistry, the presence in them of large amounts of sediments, and the high level of disturbance in their vicinities. Some may provide useful habitat when mining operations cease and succession has advanced to a point where suitable vegetation exists for food and cover. Water pumped from large mines can cause local increases in the level of the water table and can transform upland forest to palustrine wetland. Waste waters from mineral-ore mining also may acidify aquatic systems receiving them, as well as contaminate aquatic food webs with heavy metals (copper, zinc, and iron). These minerals have been actively mined in the Penobscot and Blue Hill Bay area (region 4). The Department of Marine Resources is concluding a study now in which concentrations of eight metals were monitored in two macroalgae, two polychaete, and three mollusc species. Experimental sites were established near mines, with controls in mineralized unmined intertidal areas. Preliminary results indicate that levels of three elements, Zinc (Zn), Iron (Fe), and Copper (Cu), are elevated at the mined sites. The brown algae Fucus vesiculosus exhibited mean Zn levels of up to 1288 ppm and the blue mussel contained mean values of 200 to 300 ppm Zn and 400 to 900 ppm Fe at the experimental sites, compared with control means of 79 to 80 and 500 ppm respectively. Final results of this study will be available in the near future. (See "Population and Industry" below.)

Open-pit mining of limestone (e.g., at Thomaston) produces dust that drifts to adjacent areas, sometimes increasing the alkalinity of soils and waters.

PORTS AND NAVIGATION

The major impacts of port operations and navigation projects in coastal Maine are associated with wharves, piers, dredging, and dredge spoil disposal operations.

The principal impact of wharves and piers is loss of intertidal habitat. This impact is significant in developed harbors, such as Portland (region 1), Boothbay (region 2), Rockland (region 4), Lubec (region 6), and Eastport (region 6), where relatively large areas of the intertidal zone may be covered by such structures. Piers can change local current patterns and may affect the benthic fauna adversely by changing sediment distribution and types.

An additional impact of piers and wharves is lowered productivity of benthic algae due to the shading of bottom sediment. Reduction in the productivity of benthic algae may cause a local reduction in some species. Impacts of waste water discharge associated with piers and wharves are discussed under "Population and Industry" below. Dams and wharves may provide additional substrata for epilithic algae, which may increase productivity locally.

Dredging

Dredging is the removal of land or bottom materials from wetlands, open water, or other coastal habitats (1) to obtain sand, shell, or gravel deposits, (2) to establish a commercial, industrial, or residential facility, or (3) to create or maintain channels (Metzger 1973). Most of the dredging in Maine is associated with the maintenance of commercial navigation channels and is regulated by the U.S. Army Corps of Engineers.

The areas most frequently dredged during the past 20 years are Portland Harbor, the Kennebec River, the Penobscot River, Rockland Harbor, and the Royal River. Periods between dredging operations vary from 2 to 23 years. Locations and dates of dredging projects, the cubic yards of material removed, and locations of disposal sites are given in table 3-4. Other disposal sites for private dredging exist (permits are required) and the specific coordinates of these can be found in files of the regulatory branch of the U.S. Army Corps of Engineers, Waltham, MA. Atlas map 3 depicts dredge removal and disposal sites in coastal Maine. Disposal sites in Maine are usually deep oceanic areas but are not restricted to such areas. Other disposal sites include land areas, beaches, bays, and channels in estuaries and rivers.

The basic modes of dredging are mechanical and hydraulic. Mechanical dredges generally employ a crane and a large bucket or a large power shovel to remove sediment. The spoil is dumped overboard or into a barge that is then towed to a disposal site. Hydraulic pipeline dredges pick up material by cutterhead and transport it by suction-pipe to the disposal site (Clark 1977). Dredge material (spoil) in Maine usually consists of sand, soft mud, and a small amount of rock. In Maine mechanical dredges usually are employed in Maine due to the relatively coarse nature and low volume of materials that are dredged there.

The impacts of dredging operations can be classified into two major groups: (1) those that are the result of the removal of material and (2) those that are the result of material disposal. Impacts of material removal include the loss of natural habitat, alterations of water circulation patterns, increased turbidity, the release of trapped pollutants and organic matter, and the loss of beach sediment supplies. Disposal of some dredged material (e.g., sand and rock) results in new barren habitats in upland areas and increased sedimentation on down-current substrates in open water.

Table 3-4. Summary of Federal Dredging and Disposal Projects in Coastal Maine Since 1959[a]

Region	Project location	Dates	Quantity dredged (cu yd)	Disposal area
		1979		
1	Portland Harbor	7/9/70 to 7/25/70	448,000	Ocean
		5/23/68 to 6/26/68	20,680	Ocean
		1966	20,100	Ocean
		9/65 to 6/66	2,345,000	Ocean
		8/12/64 to 3/26/65	235,029	Ocean
		10/62 to 3/63	225,000	Ocean
		1959	2500	Ocean
	Royal River	9/20/76 to 11/19/76	36,500	Land
		12/68 to 6/69	--	Land
		11/66 to 6/67	199,209	Land
2	Kennebec River	6/12/75 to 6/30/75	102,930	Channel
		6/18/71 to 6/30/71	54,534	Sequin Island
		6/68 to 7/68	32,070	River and ocean
		6/26/68 to 6/30/68	20,000	River and ocean
		7/1/67 to 7/10/67	64,200	River and ocean
		8/65	14,400	River and ocean
		9/64 to 12/64	9500	Ocean
		7/59	26,183	River and ocean
3	St. George River	8/1/77 to 8/20/77	10,000	Land
	New Harbor	12/65 to 3/66	28,961	Ocean
	Carver Harbor	8/63 to 5/64	19,000+	Ocean
4	Isle Au Haut	1979	1000 (boulders)	Ocean (north of Flake Island)
	Rockland Harbor	9/10/73 to 1/30/74	80,400	W. Penobscot Bay
		6/59 to 7/59	150	None
		4/59 to 6/59	4500	Ocean
	Belfast Harbor	7/70 to 9/70	35,786	Isle Au Haut, Ocean
	Penobscot River	7/13/68 to 7/23/68	14,500	Ocean
		6/10/67 to 6/30/67	--	Ocean
		5/26/64 to 6/13/64	74,000	Ocean
		8/15/61 to 9/11/61	114,000	Ocean
		--	74,160	Ocean

[a] Chase 1979

(Continued)

Table 3-4. (Concluded)

Region	Project location	Dates	Quantity dredged (cu yd)	Disposal area
4	Searsport Harbor	8/11/64 to 11/26/64	487,500	Ocean
	Camden Harbor	4/60	27,860	Ocean
5	Frenchboro Harbor	6/77 to 8/77	1060	Ocean-John's Island
		4/76 to 7/76	35,460	Ocean-John's Island
		6/75 to 12/75	54,000	Ocean-John's Island
	Winter Harbor	8/19/75 to 9/28/75	24,000	Winter Harbor Bay
	Narraguagus River	4/68 to 5/68	10,960	Ocean
		11/67 to 12/67	14,570	Ocean
		9/65 to 2/66	348,200	Ocean
	Bass Harbor	9/63	66,000	Ocean
	Southwest Harbor	2/62 to 4/62	None (Rock removal)	None
6	Bucks Harbor	6/12/74 to 7/10/74	62,600	Machiasport Bay
	Machias River	9/72	7760	Ocean
		3/64 to 4/64	500	None
	Pig Island Gut	10/65	60,181	Ocean
			1878 rock	
		6/65	8200	Ocean

Dredging results in the alteration or displacement of natural habitats. The exposed areas may be nearly devoid of life and are often different from the originals in physical and chemical properties (Copeland and Dickens 1974). Since most dredging produces an unstable sediment configuration, further deposition may occur and further dredging may be required. Repeated dredging prevents a community of long-lived species from becoming established in the dredged area.

Dredging also may alter the water circulation pattern. Changes in water temperature, salinity, dissolved oxygen, and sediment distribution may result. These changes are the most long-term impacts of dredging on benthic communities (Kaplan et al. 1975). Marked changes in the composition of species that have been associated with changes in sediment types resulting from dredge and fill operations have been documented (Kaplan et al. 1975). Dispersal of pelagic larvae that are carried by currents are also likely to be affected.

Excessive turbidity is another common result of dredge operations. During the operations, dredging disperses large quantities of silt into the water column. This may have detrimental effects up to a half-mile from the site (Copeland and Dickens 1974). The extent of turbidity depends largely on the type of sediment being dredged, the method of dredging employed, and the local water currents. As deposits disturbed by dredging resettle, a veneer of silt may form a false bottom that is easily resuspended by tidal and wind-driven currents. Suspended or resuspended silt may smother the sessile animals that inhabit the bottom or it may foul the respiratory apparatus of filter-feeding species (Copeland and Dickens 1974).

Excessive turbidity also decreases the penetration of light into the water column, thereby limiting plant growth and reducing primary production essential to the support of the entire food web. Reduced light penetration is of special concern in deep water, where light penetration may already be low.

Lowered primary production (photosynthesis) usually reduces the oxygen supply. The dissolved oxygen levels may be depressed further by microbial activity on suspended sediments and particulate organic materials in the water column (Clark 1977). Low levels of dissolved oxygen have been responsible for massive kills of benthic invertebrates and can place considerable stress on benthic systems around dredge sites (Radash 1976).

Zooplankton are seriously influenced by the increased turbidity resulting from dredging. Loosanoff (1961) and Loosanoff and Tommers (1948) reported that clam and oyster larvae placed in a turbid environment were affected significantly. At 0.75 g/l of silt, the growth of oyster larvae was retarded. Hoss and coworkers (1973) reported low mortality but high incidence of erratic behavior in zooplankton exposed to low concentrations of effluents from spoil disposal areas. Such altered behavioral patterns reduce reproductive success among the affected organisms.

Dredging in a polluted area can cause the resuspension of heavy metals which can be absorbed by plants and animals. When disturbed by dredging oxygen-demanding substances held within the sediments can lower levels of dissolved oxygen, a condition which may be lethal to many species (see "Water Pollution and Heavy Metals," below).

Dredging may affect fish populations in a number of ways. Spawning sites may be smothered with sediment, which either prevents spawning or covers the eggs and larvae. Spawning sites also may be removed altogether, along with the required vegetative cover. Increased sedimentation sometimes raises the biological oxygen demand (BOD) of the water, potentially reducing available dissolved oxygen to dangerously low levels. Mechanical destruction of gill filaments may occur at high sediment levels.

The exchange and transport of different types of sediment also are affected by dredging. Excavation upsets local sediment transport, when coarse-grained sediments are removed from local environments. Excavations of a small volume of material are generally inconsequential, but continued excavation of small amounts, especially on small beaches, depletes beach sediment supply. (See page 2-43, "Shoreline Erosion," in chapter 2.)

The disposal of dredge spoils is a serious environmental issue. The dumping of dredge spoil on submerged bottoms may suffocate vegetated environments, raise substrata to different intertidal heights, thereby affecting flora and fauna, and smother benthic organisms. Fill deposits in the intertidal zone are redistributed by tidal flow, increasing sedimentation on down-current substrata. In addition, turbidity and the release of trapped pollutants and organic matter may be additional problems. The U. S. Army Corps of Engineers, in their Dredged Material Research Program, have studied some beneficial uses of spoil, such as habitat creation.

The potential impacts on the food web in the areas near dredge and disposal sites include changes in nutrients and in populations of phytoplankton (producers) and benthos (consumers), which in turn affect fish, bird, and marine mammal populations. Cumulative impacts of projects may have long-term effects on species populations. Monitoring of these ecological consequences in coastal Maine has not been undertaken.

TRANSPORTATION

Ecological effects of transportation in coastal Maine are associated primarily with right-of-way corridors for railways, roads, and airports (see "Socioeconomics," chapter 2. The impacts of ports and navigation and construction activities are considered under "Ports and Navigation" above).

Some of the general impacts of roads and airports include altered surface water drainage, restricted natural flow of waters, degraded air quality, and loss of natural habitats. Runoff from impervious surfaces may include street salt, sand, motor vehicle drippings, garbage, stagnant water, and other toxic residues (Clark 1974). Roads may restrict the natural flow of water, resulting in changes in habitat. In some instances, areas of forests may become wetlands because of restricted flow of water. In other areas, the restricted flow of water may result in altered sedimentation, which may affect, for example, the benthic community in intertidal areas. Air-quality impacts associated with the use of roads are primarily local in scope and result from carbon monoxide and particulates. In addition, automobile travel in Maine, particularly during the summer tourist season, contributes to an ozone problem throughout the coastal zone (see "Air Pollution" under "Industry and Population" below).

Right-of-way corridors serve as habitat for a number of plants and birds. They are also utilized frequently by deer, foxes, and coyotes. The density of breeding birds in rights-of-way is usually less than it is in surrounding woodland and shrub habitats. The effects of rights-of-way on terrestrial bird populations is discussed further in chapter 16, "Terrestrial Birds."

Causeways builts on or over tidal areas restrict tidal flow to areas landward of the causeways. Causeways may act as barriers; most culverts do not allow a sufficient exchange of water. The alteration in drainage patterns may result in changes in water temperature, salinity, sedimentation, and flushing rates. These changes may affect primary production, benthic biota, and other organisms such as migratory birds and fishes. The passage of migratory fishes may be restricted by culverts. In extreme cases, the stagnation of water along a causeway may cause low dissolved oxygen levels, which stress aquatic fauna. Roads have caused siltation in lakes in coastal Maine (e.g., Upper Hadlock Pond, region 5). An impact associated with dirt roads, logging roads, and skid trails is soil erosion, which produces effects similar to those of agriculture and construction activities.

Roads constructed in dune areas also may have harmful ecological impacts. Construction of roads may prevent sediment from being naturally utilized as beach sediment. Roads constructed on beach ridges conflict with the natural landward migration of beach ridge material. Storms from the northeast, which occur frequently in Maine during winter, cover the road surfaces with gravel from beaches. Since the natural movement of sand is interrupted, the profile of the beach as well as the habitat for many organisms will be altered.

Airports pose a unique problem for birds, primarily gulls and waterfowl. Airports situated near dumps or along flight lines between dumps and rivers, dumps and shopping centers, or near sources of solid waste can pose a serious aircraft-bird collision hazard. Airports situated near waterbird concentration areas pose similar collision problems. Herring and great black-backed gulls, which feed and rest in open grassy habitats, are attracted to some airports. Collisions between aircraft and birds are uncommon in most areas in Maine.

Herbicides, used to control woody and herbaceous plants along rights-of-way (especially railroads), may cause problems, especially if improperly handled. Improper formulation of the herbicide and improper disposal of herbicide containers may result in locally high herbicide concentrations. These contaminants may, in turn, enter ground and surface waters. The long-term effects of herbicides on plants and animals is uncertain (see "Forestry" above).

TOURISM AND RECREATION

Tourism and recreation in coastal Maine have a significant impact on the environment, through (1) the discharge of wastes, (2) the disturbance of and encroachment on sensitive species of wildlife, and (3) the alteration of natural ecosystems. Seasonal residences and tourist facilities (motels, hotels, and restaurants) add to the pressures of development on lands. Their waste water and domestic sewage contribute to the seasonal and permanent closings of clam and worm flats. The sanitary survey reports prepared for each municipality by the DEP summarize the number of residential discharges and include a list of the clam flats closed because of pollution from domestic sewage (see "Water Pollution" under "Industry and Population" below). Subdivisions of land allow human activities in areas that were previously less disturbed. These impacts are discussed further under "Industry and Population" below. Other impacts result from seasonal and localized increases in population, which results in concentrated activity that may degrade the natural environment. Mechanical equipment such as snowmobiles, motor boats, and ski lifts contribute to this impact.

Power boating creates waves which may disturb birds nesting in rivers, wetlands and lakes (e.g., loons). Power boating also creates short-term suspended sediment concentrations and hydrocarbon deposits in the water column. Snowmobiling, truck camping, and vehicular traffic on dunes and salt marsh surfaces promotes devegetation and accelerated wind and current erosion.

The trampling of vegetation in fragile ecosystems, such as ericacious bogs, salt marshes, islands and dunes, has effects for which the recovery process requires many years. Continuous or unmanaged traffic in dune and marsh areas promotes devegetation and, thus, erosion by winds and currents.

Rare plant collecting and the picking of wildfowers threaten many of the aesthetically attractive rare plant species. (See chapter 20, "Endangered, Threatened, and Rare Plants" for a more detailed discussion of recreational activities that adversely affect rare plants.)

Bird breeding areas (i.e., bald eagle, osprey, common loon, seabird, and shorebird), shorebird roosting areas, and seal haulout sites are particularly vulnerable to pressure from human recreational activities. Atlas map 4 plots known important wildlife areas in coastal Maine. The impact of human disturbance on breeding bald eagles is discussed in chapter 16, "Terrestrial Birds," and on breeding seabirds and shorebirds in chapter 14, "Waterbirds." The latter chapter also discusses the impact of human disturbance on roosting shorebirds.

SPORT FISHING AND HUNTING

The most important ecological effect of sport fishing and hunting is the direct harvest of fish and wildlife. Other impacts may be significant locally. Construction of fishing piers, boat launching ramps, and recreational camps may result in localized pollution. The effects of piers are discussed under "Ports and Navigation" above.

Vehicular traffic to inlet fishing areas devegetates salt marsh and dune surfaces, promoting accelerated erosion. Continual emplacement of hunting blinds on some marsh plots promotes salt panne formation or accelerated tidal current erosion.

The use of lead shot may be a significant hazard to waterfowl, and to large raptors which prey upon wounded waterfowl (i.e., eagles and peregrine falcons). Lead pellets have been found to occur in significant quantities in the sediment of Merrymeeting Bay (region 2). Analyses of gizzard contents of ducks shot on the Bay revealed one or more lead shot in 8.1%, 6.1%, and 6.4% of the black ducks examined in 1976, 1977, and 1978 respectively. Lead shot causes lead poisoning, which can weaken, debilitate, and kill birds. A carefully designed survey conducted just 2 weeks before the 1977 hunting season began indicated that over 41,000 lead pellets per acre (101,000/ha) were present in the top 2 to 4 inches (5 to 10 cm) of soil in the intertidal area of Merrymeeting Bay (region 2; personal communication from J. R. Longcore, U.S. Fish and Wildlife Service, Orono, ME; April, 1979).

INDUSTRY AND POPULATION

The release of organic and inorganic wastes and the modification of natural habitats are the most pronounced ecological stresses of industry and population in coastal Maine. The effects of water pollution, air pollution, oil pollution, surface water control, and construction are discussed below.

Water Pollution

The extent of water pollution in coastal Maine is difficult to describe accurately, because comprehensive data on the number, types, and amounts of substances discharged are unavailable. Licenses have not been issued for all discharges for which they are required, and all of those licensed are not monitored. Among those that are monitored, all components of the discharge are not monitored. Most water pollution in Maine is in rivers and estuaries below large towns.

Four classes of waste water discharges are monitored by the Maine DEP: industrial, municipal, commercial, and residential. Industrial and municipal dischargers produce the largest amount of effluent. The exact amounts of effluent cannot be determined due to variations in effluent flow. Furthermore, license data do not include inactive or expired licenses. Most inactive licensed activities produce effluent seasonally (summer), and many discharge facilities whose licenses have expired still are producing effluent (personal communication from L. Fontaine, Maine Department of Environmental Protection, Augusta, ME; December, 1979). Municipal and industrial dischargers may have local impact and cumulatively may have impacts on lakes, rivers, estuaries, and bays. Atlas map 3 shows the locations of permitted industrial and municipal discharges. A list of these point sources is given in appendix A.

Water pollution has a major impact on the clam industry, the State's second most important fishery. Each year an average of 9658 acres (3910 ha), or 21% of the State's clam flats, are closed due to bacterial pollution. Closures in the characterization area vary from 9% in Washington County (region 6) to 71% in Sagadahoc County (region 2; Maine State Planning Office 1978). This situation has developed in coastal Maine because of the inadequacy of soil (thin overburden and near-surface bedrock) for septic systems and the general lack of centralized sewage treatment facilities. The impact is especially acute in the summer, when the numerous cottages that line the shore in many areas are occupied. A survey of residential point sources adjacent to intertidal shellfish flats revealed that only about 56% were licensed by the DEP (Winters and Fuller 1980). The latter authors have prepared maps showing waste-water discharge locations (point sources of pollution; primarily residential) in each coastal community. Each report summarizes the pollution status, size, production (in terms of bushels per acre), and cash value of each currently producing shellfish area, by town. These reports are valuable because they identify pollution problems, their causes, and economic impact.

Reports on all coastal towns west of Milbridge have been published. Reports on all coastal towns east of Milbridge will be published in 1980.

All major rivers and streams, great ponds, and tidal waters have been classified according to their water quality status (Maine Department of Environmental Protection 1977). The classification of coastal Maine surface waters is presented in appendix B.

Areas in coastal Maine with critical water quality problems have been identified (U.S. Environmental Protection Agency 1978). Included are 15 sections of 13 rivers and estuaries in the characterization area (figure 3-1; table 3-5). Critical water quality problem areas have such severe pollution loading and/or minimal assimilative capacities that fishable/swimmable water quality will be below standard even after all point sources are under control. The primary causes, either singly or in combination, for the critical water quality problems remaining in coastal Maine are: combined sewer outflows (all 15 areas); municipal discharges (2 areas); industrial discharges (2 areas); and low flow caused by flow regulation (1 area).

Other related factors are nonpoint source loadings (agricultural and urban runoff) and toxic substances. The amount of information available on toxic substances is limited.

Water pollution has been traditionally, and continues to be, of concern in coastal Maine. The ecological impacts of water pollution include bacterial contamination of commercial clam flats, low dissolved oxygen, increased turbidity, eutrophication, and temperature alteration in water bodies, and pollution by oil, hazardous wastes, PCBs, and heavy metals.

Bacterial pollution. Bacterial pollution has accounted for the closure of 56% of the clam flats in the State of Maine. It has a severe economic impact on the clam fishery and a potential effect on public health. However, effects of bacterial contamination on clams, invertebrates, and other organisms in the food chain are not evident (personal communication from P. F. Larsen, Bigelow Laboratory for Ocean Sciences, Boothbay Harbor, ME; February, 1980).

Dissolved oxygen. The utilization of organic wastes by microorganisms in aquatic systems requires large amounts of oxygen (Clark 1977). An increase in demand for oxygen because of organic wastes sometimes may lead to dangerously low levels of oxygen in the sediments or in the water column above the sediments (Clark 1977). If low levels of dissolved oxygen persist, most animals die. Deoxygenated areas are recolonized by less desirable species that are tolerant of low levels of oxygen (Grassle and Grassle 1974).

Serious oxygen depletion in sediments is often caused by effluents from pulp and paper mills. The floating components of the effluent prevent light from reaching the phytoplankton and thereby reduce the amount of oxygen that is produced photosynthetically. During summer the biodegradation of the pulp fibers, sawdust, wood chips, and other organic wastes of the wood products industry can deplete the dissolved oxygen in the sediment and in the deeper layer of the water column (Poole et al. 1977), adversely affecting fish, invertebrates, and other aquatic organisms.

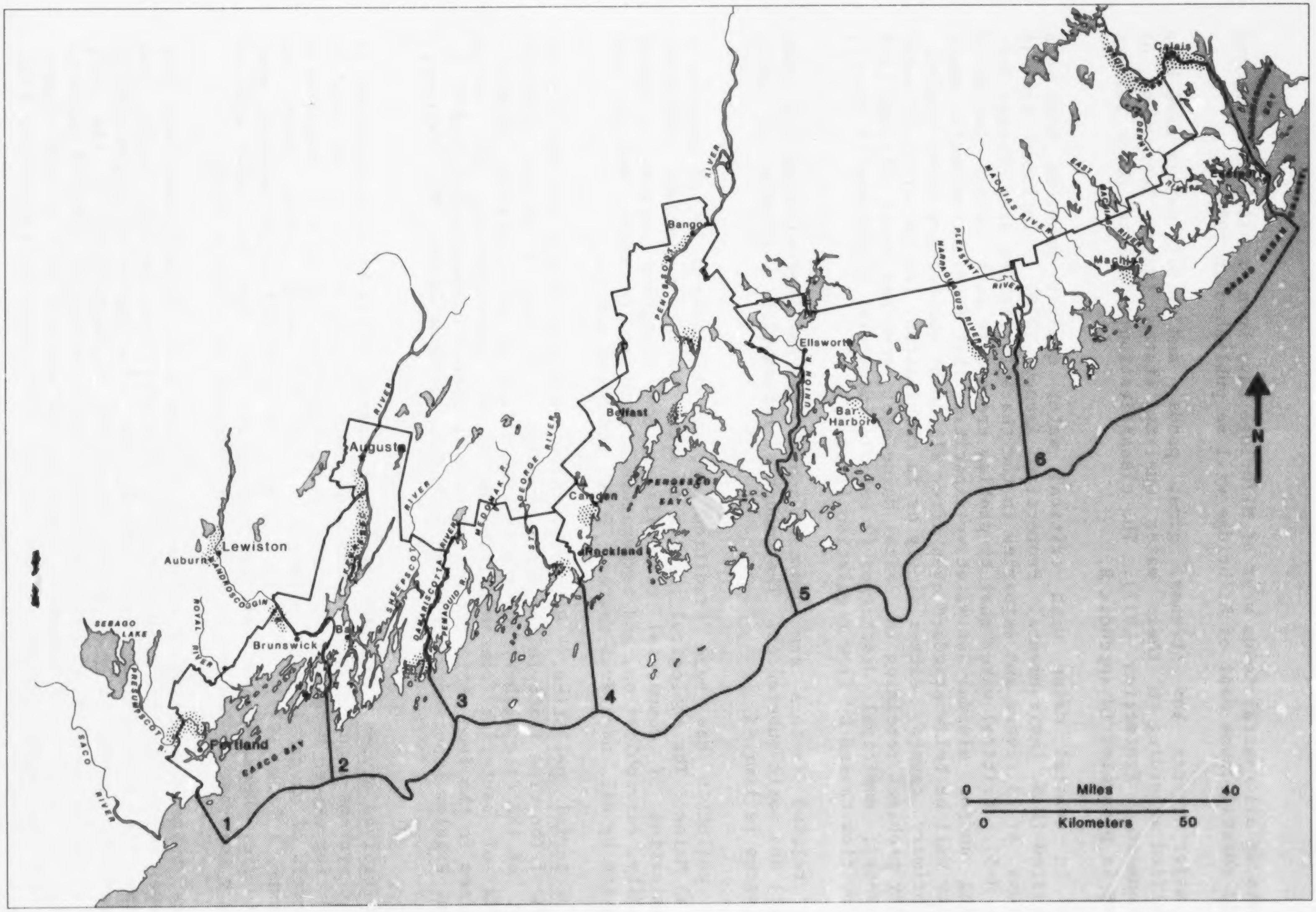

Calais
DENNYS
Eastport
GRAND MANAN CHANNEL
EAST MACHIAS RIVER
MACHIAS RIVER
Machias
PLEASANT RIVER
NARRAGUAGUS RIVER
Bangor
PENOBSCOT
RIVER
Ellsworth
UNION R.
Bar Harbor
Belfast
Camden
PENOBSCOT BAY
Rockland
ST. GEORGE RIVER
MEDOMAK R.
PEMAQUID R.
DAMARISCOTTA RIVER
SHEEPSCOT RIVER
KENNEBEC
RIVER
Augusta
Lewiston
Auburn
ANDROSCOGGIN
Bath
Brunswick
ROYAL RIVER
SEBAGO LAKE
PRESUMPSCOT R.
Portland
CASCO BAY
SACO RIVER
1
2
3
4
5
6
N
0
Miles
40
0
Kilometers
50

Figure 3-1. Areas in coastal Maine with critical water quality problems (dotted; U.S. Environmental Protection Agency, 1978).

Table 3-5. Critical Water Quality Problem Areas in Coastal Maine, 1978[a]

Region	Water body	Location	Length (mi) not expected to meet fishable/ swimmable goals by 1983	Problem	Causes of water problems
1	Fore River - Portland Harbor	Portland	.25±	Coliform solids	Combined sewers: Portland
	Presumpscot River	S.D. Warren Outfall in Westbrook to head of tide in Falmouth	7	Dissolved oxygen, fecal coliform solids	Municipal discharges: Westbrook Industrial discharges: S.D. Warren Paper Mill Combined sewers: Westbrook Low flow (flow regulation Benthic demand
2	Boothbay Harbor	Boothbay	.25±	Coliform solids	Combined sewers: Boothbay
	Kennebec River	Bath	1±	Coliform solids	Combined sewers: Bath
	Kennebec River	Augusta to Richmond	15	Coliform solids	Combined sewers: Augusta, Hallowell, Farmingdale, Gardiner, Randolph, Richmond
4	Camden Tide Waters	Camden	.25±	Coliform solids	Combined sewers: Camden
	Castine Harbor	Castine	.25±	Coliform solids	Combined sewers: Castine
	Penobscot River	Brewer, Bangor	2±	Coliform solids	Combined sewers: Brewer, Bangor
	Penobscot River Estuary	Bucksport	.25±	Coliform solids	Combined sewers: Bucksport
	Rocklock Harbor	Rockland	.25±	Coliform solids	Combined sewers: Rockland

[a] U.S. Environmental Protection Agency 1978.

(Continued)

Table 3-5. (Concluded)

Region	Water body	Location	Area (miles) not expected to meet fishable/ swimmable goals by 1983	Water quality problems	Causes of water problems
4	St. George River	Thomaston	.25±	Coliform solids	Combined sewers: Thomaston
5	Bar Harbor - coastal waters	Bar Harbor	.25±	Coliform solids	Combined sewers: Bar Harbor
	Narraguagus River	Milbridge	.25±	Coliform solids	Combined sewers: Milbridge
6	Machias River	Machias	.25±	Coliform solids	Combined sewers: Machias
	St. Croix River	From Georgia Pacific outfall in Woodland to tidewater in Calais	10	Dissolved oxygen, solids, coliform	Municipal discharges: Baileyville and Calais Industrial discharges: Georgia Pacific Combined sewers: Baileyville and Calais

Turbidity. Suspended and settleable solids resulting from sewage effluent may increase turbidity. Decreased light penetration into water, because of particulate loads, decreases primary production. On the bottoms of water bodies, particulate loads can render surfaces unavailable for attachment of plants and invertebrates.

Benthic invertebrates are affected by wastes containing settleable and suspended solids. Silts and clays are a significant fraction of discharged wastes. The impact of these particulates on benthic invertebrates is discussed above under "Dredging."

Eutrophication. Input of nutrients to water bodies by municipal, residential, and commercial dischargers has effects similar to those described under "Agricultural Impacts" above. Nutrients may accelerate the growth of algae and vascular plants in lakes. The resultant increases in decomposition causes more oxygen to be consumed than lakes can produce. This situation speeds up eutrophication, which can result in oxygen depletion and, in extreme cases, fish kills. Annabessacook Lake, Pleasant Lake, and Togus Pond (region 2) are examples of eutrophic lakes.

Palustrine areas entrap nutrients in peat, thereby slowing the rate of eutrophication in lakes downstream. Palustrine areas also export nutrients and organic matter downstream. Excessive nutrients in a palustrine wetland can accelerate plant succession.

Since stream and river waters are in motion, sewage-derived nutrients do not remain in the vicinity of the point source for long periods of time. Eutrophication, therefore, is normally less severe in streams than in standing water (lacustrine and palustrine systems).

Sewage-derived nitrogen can lead to the production of excessive blooms of phytoplankton in riverine, estuarine, and marine systems in the summer months (Carpenter et al. 1969). The type of sewage treatment (primary or secondary) influences the impact. Primary sewage is low in the form of nitrogen that is readily usable by phytoplankton, but secondary sewage is high in this type of nitrogen. The flushing characteristics of receiving waters is critical in determining the consequences of point-source discharges of sewage.

Heavy metals. Although coastal Maine is not as industrialized as the rest of the Eastern U.S., heavy metal concentration in the estuarine suspended particulates, biota, and sediments appears to be comparable in some locations to that in heavily industrialized areas (personal communication from L. K. Fink, University of Maine, Walpole, ME; January, 1979). Of the aquatic systems, the riverine and estuarine systems are affected most by heavy metals, because most waste-water point sources discharge into these systems. The terrestrial, lacustrine, and palustrine systems receive most of their heavy metal input from particulate air pollution. In addition, they may receive inputs from landfill sites, from oil pollution, and from herbicide application. Courtemanch (1977) report that the use of a copper-containing herbicide to reduce algal blooms in Silver Lake (region 4) caused severe disruption of benthic fauna. Heavy metals commonly are introduced through industrial and municipal outfalls, dumping sites, dredging sites, agricultural and urban runoff, fungicides, germicides, heating or burning of fields, mining operations, and oil discharges from ships. The discharge of sewage and sewage sludge is considered a prime source of heavy metals (Clark 1977). In Maine, pulp plants are major sources of heavy metals (Fink et al. 1976). Chromium, lead, copper, and zinc are the principal metals discharged from these plants. Also, naturally occurring sediments derived from metal ore deposits contain toxic heavy metals, including chromium, manganese, cobalt, nickel, copper, zinc, lead, arsenic, mercury, silver, cadmium, and vanadium.

Very little site-specific data on heavy metal concentrations are available for coastal Maine waters. Fink and coworkers are sampling five Maine estuaries for heavy metal contamination (personal communication from L. K. Fink, University of Maine, Walpole, ME; January, 1979). Their data will establish baseline levels for 10 metals. A Maine Department of Marine Resouces (MDMR) study indicates that concentrations of heavy metals in macroalgae and shellfish are elevated at sites near mining operations (see "Mineral Extraction " above).

Fink's preliminary conclusions indicate that the heavy metals in coastal waters are industrial in origin. Levels of five metals found by Fink and coworkers (1976) in suspended particulate matter in the St. Croix River estuary, which is subjected to paper mill effluent, are listed below:

Element	Range(ppb)	Mean(ppb)
Chromium	40- 373	117
Copper	21-2153	507
Iron	4-69	38
Manganese	139-1059	605
Lead	21-1799	324

Maine Department of Environmental Protection waste-water discharge licenses specify the amounts of various heavy metals that a discharger may release; these data are given in appendix A. The amount of heavy metal input from acid precipitation is unknown. Acid precipitation is further discussed under "Air Pollution" below. Heavy metals have been found to contaminate landfill sites in Maine (Emmons 1978). Heavy metal levels in vascular plants are used to measure contamination.

Concentrations of heavy metals approaching or exceeding EPA standards for toxicity to several organisms have been found in several Maine estuaries that are near metal ore bodies and mining operations (Hurst and Dow 1972) and that receive pulp manufacturing effluent (Fink 1977).

Heavy metals tend to be associated with the organic fraction of estuarine bottom sediments (Fink et al. 1976). Metals are transported through the environment by sorbing (adsorbing and absorbing) onto the organic solids and the subsequent sedimentation, resuspension, or current dispersion of the particulate organics (Clark 1977). However, dispersal of heavy metals from the source of input generally does not occur. Thus, little exchange of heavy metals takes place between the estuarine and marine systems. However, the movement of sediments in dredging operations may transport heavy metals from estuaries to marine environments (see "Ports and Navigation" above). The most frequently dredged areas in Maine receive drainage from the most industrialized portions of the State.

Heavy metals are a major concern from the point of view of human health. Since heavy metals may concentrate in the tissues of marine food organisms, a person eating enough contaminated seafood or fish over a period of time could develop heavy metal poisoning. For example, organic mercury has been cited as the cause of minamata disease in Japan (Clark 1977).

The effects of heavy metals on marine and estuarine invertebrates are modified by salinity, dissolved oxygen, temperature, pH, the presence of other toxicants, the form of the metal, and the age and condition of the organism. Laboratory experiments indicate that these factors owe their influence to the variable rates at which metals are absorbed (Bryan 1971). No evidence of damage to macroalgal communities by heavy metals has been documented.

Little information appears to exist on the accumulation effects of heavy metals in sea grasses (Thayer et al. 1975). Barsclate and coworkers (1975) found that dissolved copper may be removed from overlying water by eelgrass.

Mercury in North Atlantic zooplankton collections has been studied by Windom and coworkers (1973), who collected samples from the New York Bight south to Cape Hatteras. The species composition of the plankton varied considerably, although most samples were composed of copepods and chaetognaths. The concentration of mercury appeared to bear little relation to species composition, but it was determined that nearshore zooplankton were higher in mercury content than those offshore. Concentrations reached as high as 5.3 ppm in the New York Bight in contrast to values of 0.1 to 0.3 ppm in offshore areas. Mercury appears to be concentrated to a similar degree by different organisms in the plankton community. This may be due to passive rather than active uptake.

Sublethal effects of heavy metals can be grouped into morphological changes, inhibitory effects, and behavioral changes. Some effects of metals, such as the bright green color of oysters that results from accumulated copper in the tissues (personal communication from P. F. Larsen, Bigelow Laboratories, W. Boothbay Harbor, ME; February, 1980), may be recognized visually. Zinc and copper are metals necessary for normal growth but elevated levels can lead to inhibition of growth. Abnormal structural morphology has been observed in the larvae of sea urchins having slightly elevated concentrations of copper and zinc (Bryan 1971). In addition to inhibiting growth, heavy metals may prevent the settlement of larvae, delay or prevent sexual development, and inhibit feeding. Although laboratory experiments usually are performed on hardy species, abnormal behavior has been observed in invertebrates exposed to concentrations of copper, silver, or zinc that are only one order of magnitude higher than those of sea water. Larval forms may be affected at even lower concentrations (Bryan 1971).

Although little is known about the effects of heavy metals on ecosystems, it has been estimated that when metals such as copper, silver, and zinc reach a concentration ten times that of sea water, serious detrimental effects may occur (Bryan 1971). Suspension-feeding animals, such as clams, mussels, and oysters, are extremely susceptible to accumulation of metals and, thus, are valuable for monitoring ecosystems (Fink et al. 1976). Sediments retain high levels of metals. These metals then may be taken up by organisms and passed to higher trophic levels (Bryan 1971). For example, the Penobscot River has been cited as having high levels of mercury. Also, eels from the Penobscot have relatively high mercury levels. Eels, in turn, are fed upon by eagles, directly or indirectly (eels serve as prey for common mergansers, which are eaten by eagles). Recent mercury levels in bald eagle eggs are among the highest ever recorded. Mercury contamination results in thinning of eggshells and embryo mortality.

Thermal pollution. Heated waters, when discharged into the environment, raise the temperature of the receiving water. The extent to which the temperature is raised depends upon the amount of heated discharge, the amount of diluting water available, and the mixing rate. Heated discharge may come from sources such as nuclear power generation, oil power generation, heavy machine operations, industrial operations, and even fish hatchery operations. The magnitude of the thermal impacts depends on the location and frequency of activity. Cold water may be discharged from large, deep impoundments.

Industrial point sources, including power generation, are the largest contributors of thermal pollution in the coastal zone. Approximately 1 billion gallons of thermally treated water enter the characterization area every day. Montsweag Bay in region 2 receives 85%, while Penobscot Bay in region 4 and South Portland Harbor in region 1 receive 11% and 4%, respectively (table 3-6).

Thermally treated water affects the physiological functions and behavior of certain aquatic organisms (e.g., phytoplankton, benthic invertebrates, and

Table 3-6. Major Thermal Discharges in the Characterization Area from Combined Industrial and Municipal Point Sources[a].

Region	Amount (millions gal/day)	% of total	Receiving water body and temperature range
1	47	4	S. Portland Harbor 100° to 210°F
2	927	85	Montsweag Bay 116° to 180°F
3	<1	<1	Medomak River 84° to 85°F
4	118	11	Penobscot River 60° to 120°F
5	0	0	-----
6	<1	<1	E. Machias River 97°F
Total	1092	100	

[a] Maine Department of Environmental Protection files.

fish) by increasing their metabolic rates and by reducing the solubility of oxygen. The accelerated biological activity demands increased oxygen, which may result in low levels of dissolved oxygen. In general, water temperature controls spawning and hatching of fish and aquatic invertebrates, regulates their activity, and stimulates or suppresses growth and development (Jaine et al. 1977). In addition, rapid changes in temperature can kill organisms. Winter shutdown of a power plant is particularly likely to result in severe thermal stress and possible mortality in organisms that have become acclimated to warm conditions created by thermal discharge.

High volumes of thermal waste discharged into small bodies of water with relatively little current may become the primary mixing force and increase flushing rates, which could induce higher sedimentation. The effects of increased sedimentation in estuarine systems are discussed under "Dredging" above.

Small changes in water temperature changes (<5°C) probably have little or no effect on phytoplankton populations, since temperature change is relatively small after the heated water is mixed with riverine, estuarine, and marine water. Mortality to phytoplankton due to entrainment was insignificant at Maine Yankee Atomic Power Plant in Montsweag Bay (McAlice et al. 1978).

In recent years, Vadas and coworkers (1976) have produced a long-term data base on growth and reproduction of Maine macroalgal populations before and during exposure to heated discharges and in unexposed control areas. They examined the effects of thermal discharges from Maine Yankee Atomic Power Plant in Wiscasset (region 2). Compression of the intertidal macroalgae into narrower and less dense bands was found in areas of heated discharge; this did not take place in control areas (Vadas et al. 1976). The dominant intertidal algae (Ascophyllum nodosum and Fucus vesiculosus) showed some rearrangements and the growth of A. nodosum sometimes was stimulated in areas receiving heated effluent. While floral composition may be altered extensively on some coasts (North 1969; and Wood and Zieman 1969), no loss of macroalgal species due to thermal loading was found in Maine.

The effects of thermal loading on eelgrass are poorly understood. Within areas with restricted temperature limits, higher temperatures could stimulate growth (Thayer et al. 1975). At higher temperatures, however, plants may undergo heat stress. Available data suggest that in areas farther south than Maine (Dillon 1971) eelgrass has a higher temperature tolerance (30°C; 86°F), while populations on Mt. Desert Island (region 5) may undergo heat stress at temperatures above 20°C (68°F; Setchell 1929).

The effects of power plants on zooplankton, including fish and shellfish larvae, have been studied intensively. Planktonic organisms carried into cooling systems by water intake mechanisms pass through the intake screens and the condensers and are discharged into the plume. These organisms are not only subjected to short-term elevated temperatures, but they may be killed by mechanical devices, pressure changes, and exposure to chemicals as they pass through the power plant. Studies have shown that zooplankton mortality from passing through the cooling system varies considerably, from as low as 8% to as high as 95% (e.g., Heinle 1969; Barnett and Hardy 1969; Brooks 1970; Johns Hopkins University 1970; Hair 1971; Kelly 1971; Ryther et al. 1973; Carpenter et al. 1974; Normandeau Associates 1974; and Nelson et al. 1976). Under some conditions, this may have a significant impact on local fish populations. Some adult fishes of many species suffer impingement, even though they can swim against the flow of intake water (Marcy 1976).

Changes in zooplankton populations in large bodies of water receiving heated effluents have not been observed in two intensive studies in Montsweag Bay (McAlice et al. 1970-1977) and in Pennsylvania (Schuler 1970-1976). These studies suggest that, at least in the above areas, temperature increases from power plant discharges are too small to have significant effects on the zooplankton population. This may be a result of proper design and location of the power facilities and discharge plumes studied.

According to Burton and coworkers (1976), the thermal effects on benthic organisms either directly or indirectly are very localized and present little change in species composition over large areas. Water temperature changes (i.e., 2° to 5° C; 4° to 9° F) will have the most serious effect on species that are living close to their thermal limit which is probably true of a few Maine species (e.g., the quahog; Larsen, unpublished). Benthos, which are normally exposed to greater temperature variations in the intertidal and estuarine environments, are more resistant than subtidal marine organisms to the harmful effects of temperature fluctuations (Prosser 1973).

Benthic communities may be stressed by low dissolved oxygen levels caused by high summer water temperatures and heated effluent.

Marked changes in number and composition of species have been associated with areas receiving water heated 6 to 10°C (11 to 18°F) higher than normal (Logan and Maurer 1975). However, these effects on benthos are minimized, since heated water is less dense and rises as it moves away from the source (Warinner and Brehmer 1966).

Benthic studies of sedentary fauna in Montsweag Bay showed no evidence of significant detrimental effects that could be attributed to the discharge of thermal effluents from Maine Yankee Atomic Power Plant (Dean and Ewart 1978).

No major adverse effects have been noted on larval polychaetes entrained in the cooling effluent of Maine Yankee Atomic Power Company; however, effects on the other major taxa have not been studied.

PCBs. PCBs are long-lived organochlorines that are not soluble in water. Once in a system, PCBs rapidly become bound to living or dead organic matter or to bottom sediments. They are mostly industrial byproducts and still are entering aquatic systems in the U.S. in large amounts (Ohlendorf et al. 1978). Most PCBs enter the aquatic systems through industrial waste, sewage, sludge, electrical transformers and conductors, and the burning of plastics. They occur in highest concentrations around highly industrialized areas (Howe et al. 1978).

PCBs are toxic to aquatic invertebrates and vertebrates (Duke et al. 1970; and Hanson et al. 1974) and can be transferred and accumulated in food webs, which may include people (Sayler et al. 1978). (Bioaccumulation is the accumulation of a substance in an animal at a greater concentration than in its food or the next lower trophic level so that the members of the highest trophic level within a food chain have the highest concentration.) PCBs have been reported to inhibit growth of phytoplankton populations (Fisher et al. 1973) and interfere with protozoan chemotaxis (response to chemical stimuli; Walsh and Mitchell 1974). They can stimulate and inhibit bacterial growth (Bourquin and Cassidy 1975; and Keil et al. 1972). No evidence exists that bacteria in their natural environment can metabolize and break down PCBs (Sayler et al. 1978).

PCBs can concentrate in the tissues of certain species directly from the environment as readily as it bioaccumulates via food. Benthic invertebrates and zooplankton bioconcentrate PCBs. PCBs pose a potential health hazard to people because they accumulate in sediment where bioconcentration by commercially important benthic species such as lobsters, soft-shelled clams, and blue mussels, occurs (Edwards 1977).

A preliminary inventory in coastal Maine in the mid-1970s failed to show PCB contamination in estuarine and marine sediments or in certain estuarine and marine organisms (personal communication from J. Hurst, Maine Department of Marine Resources, W. Boothbay Harbor, ME; April, 1979). More recently, PCBs were detected in blue mussels from four locations along the Maine coast (Council on Environmental Quality 1979). The levels measured at each site were: 15 ppb at Blue Hill Falls (region 4); 80 ppb at Sears Island (region 4); 55 ppb at Cape Newagen (region 2); 60 ppb at Bailey Island (region 1); and 95 ppb at Portland (region 1). Also, PCBs have been found in eggshells of bald eagles in Maine (see chapter 16, "Terrestrial Birds").

Studies in Scotland have shown that PCBs may accumulate in small amounts in macroalgae growing in areas exposed to PCB pollution (Parker and Wilson 1975). These may be transferred to grazers, such as limpets and sea urchins, which in turn are prey for certain waterbirds (i.e., purple sandpipers, herring gulls, and common eiders). Bioaccumulation of PCBs in birds interferes with reproduction. The effects of PCBs on seabirds, wading birds, bald eagles, and marine mammals are discussed in chapter 14, "Waterbirds," chapter 16,"Terrestrial Birds," and chapter 13, "Marine Mammals."

The resuspension and redistribution of PCBs by dredging can increase PCB concentrations to critical levels (Maurer et al. 1974; see "Dredging" under "Ports and Navigation" above).

Air Pollution

Substances that pollute the air are released by factories, power plants, and motor vehicles. Polluted air is also transported to Maine from other parts of the country by winds. Control of air pollution in Maine includes cleansing the local point sources and relying on other areas of the country to keep their air pollution levels low.

Air pollution is greatest in and around large cities, where the automobile is the chief polluter. In small towns, air pollution is derived mostly from industrial point sources and from stationary fuel-combustion. In rural areas, most of the air pollution is transported from more populated areas or arises from large individual point sources.

Although the air quality in coastal Maine is generally good, areas exist that do not meet the criteria set forth by the EPA in the National Ambient Air

Quality Standards (NAAQS) and that pose potential threats to the health of organisms (including people) and to the environment (NAAQS and the Clean Air Act and its application to coastal Maine are described in appendix C). In addition, areas exist that are unclassified; the quality of their air is not known.

The Maine State Implementation Plan of 1979 identified (based on extant ambient air quality data) those portions of the coastal zone that have not attained safe levels of the five pollutants controlled by the Clean Air Act: sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), total suspended particles (TSP), and ozone (O_3). Ozone represents a particularly serious problem as the entire coastal zone has unsafe levels of it. Several areas have unsafe levels of TSP and CO. Coastal Maine has been classified as having safe levels of NO_x and unsafe levels of SO_2. Maine suffers from acid precipitation that is the result of long-distance transport of SO_2 and NO_x from other areas. Parts of region 4 and all of regions 5 and 6 were classified as "nonattainment" with regard to SO_2 in 1977, because of large amounts released in Millinocket, Maine (in violation of NAAQS). Regions 4, 5, and 6 are currently in "attainment." Part of region 4 and all of regions 5 and 6 will be reclassified with regard to ozone. Due to lack of data and a change in NAAQS standards for ozone this area will be classified as "unclassifiable."

Attainment areas are classified by the EPA as class I, class II, or class III, depending on the current quality of the air and the degree of deterioration to be allowed for in these nondegradation areas. Maximum allowable increases in ambient concentrations of pollutants have been set. Class I areas include all national and international parks, national wilderness areas, and national memorial parks >6000 acres (2429 ha). These areas are highly protected. All other attainment areas in coastal Maine are class II.

The individual statuses of the five criteria air pollutants controlled by the Clean Air Act and the biological effects of air pollution in coastal Maine are discussed below.

Sulfur dioxide. Gaseous sulfur dioxide (SO_2) is emitted primarily by combustion in coal- and oil-burning power plants and to a lesser extent by pulp mills and residential and commercial heat generators. Sulfur dioxide is oxidized in the atmosphere to sulfuric acid, which is carried in precipitation and causes rain water to be acidic. The mean residence time for sulfur in the atmosphere is 2 to 4 days (Robinson and Robbins 1968). Consequently, SO_2 may be transported more than 4375 miles (7000 km) before deposition occurs (Likens and Bormann 1974). Ecological damage to natural systems from acid rain has been documented in New York, where many remote lakes have become devoid of fish, due to low pH caused by acid rain. Similar problems were documented in northern New England in 1979 (personal communication from T. Haines, U.S. Fish and Wildlife Service, Orono, ME; December, 1979). Recent studies (Davis et al. 1978; and Norton et al. 1978) indicate that transport of SO_2 into Maine, from sources as far away as the Ohio Valley, is causing ecological deterioration (acidification), particularly in lakes.

The characterization area presently maintains an attainment rating for SO_2. State officials have indicated that total reduced sulfur, present in the air as H_2S and other substances, is problematic chiefly due to its odor, and the

EPA has asked Maine to set a standard for existing sources by July, 1980. This standard will affect paper and pulp mills (personal communication from John Chandler and David Dumas, Department of Environmental Protection, Augusta, ME; August, 1979).

Nitrogen oxides. Nitrogen oxides (NO_x) are products of combustion (e.g., from automobiles and furnaces) and to a lesser extent commercial chemical production. When oxidized in the atmosphere, nitrogen oxides produce nitric acids, which contribute to the low pH or acidity of rain. Nitrogen oxides are emitted in lesser quantity than sulfur oxides. The entire State of Maine, including the coastal zone, has attained safe levels of for NO_x . In fact, the State has nc standard for NO_x, since approaching the Federal standard has not been difficult. The EPA expects no NO_x increases in Maine in the near future (personal communication from Norman Beloin, Environmental Protection Agency, Lexington, MA; July, 1979). Nitrogen dioxide can be transported over long distances.

Carbon monoxide. Carbon monoxide (CO) is a gas produced by combustion. The greatest source of carbon monoxide is the combustion products of gasoline engines of automobiles. Carbon monoxide is a localized pollutant, most toxic in the immediate vicinity where it is produced, particularly in areas of heavy traffic and restricted air flow such as commercial areas, intersections, and interchanges on specific streets.

Within the coastal zone only parts of Bangor presently have nonattainment status with regard to carbon monoxide (Maine Department of Environmental Protection 1979). In Bangor, violations of the 8-hour standard have totaled 159 from 1974 through 1977 in the downtown area (Maine Department of Environmental Protection 1979). Portions of Augusta and Portland may have unsafe levels of CO, because of the high volume of automobile traffic in these cities (both cities currently are not monitored for CO). High volumes of traffic in summer compound air quality problems.

Particulates. Particulates are defined as particles in the air, including soot, mists, and sprays. Particulates may be nontoxic materials, such as dirt and dust, or toxic materials, such as lead, asbestos, hydrocarbons (which may be carcinogenic), suspended sulfates, nitrates, and, possibly, radioactive elements. Particulates are measured as total suspended particulates (TSP) and the major sources are road dust from traffic, rubber tire wear, unpaved parking lots, tailpipe emissions, construction/demolition, smelters, fertilizing processes, and power plants (U.S. Environmental Protection Agency 1979). Emissions from wood-burning stoves also contribute an unknown amount of particulate material to the atmosphere.

In Maine, five areas exist that have nonattainment status and four areas that are unclassifiable for particulate emissions. Three of the nonattainment areas, Augusta, Rockland/Thomaston, and Bangor/Brewer, are within the characterization area. Bath is unclassified with regard to TSP.

Ozone. Ozone is not emitted directly into the atmosphere but results from a reaction between nitrogen dioxide and hydrocarbons in the presence of sunlight. Hydrocarbons, which are emitted as exhaust fumes from motor vehicles and from industrial sources, are the most significant contributors to ozone formation. Ozone and its precursors can remain in the atmosphere for long periods of time and consequently are subject to long-distance transport.

Ozone and its transport into the State from large metropolitan areas to the southwest is a significant problem in Maine. The entire coastal characterization area has nonattainment status with regard to ozone. Ozone transport into Maine is particularly severe in the warmer months of the year, when the prevailing winds are from the southwest. Automobile travel in Maine, particularly in the tourist seasons, contributes to the ozone problem. The Portland area, with its large number of petroleum bulk stations and terminals, contributes greatly to the ozone problem through the evaporation of volatile organic hydrocarbons. Measurement of ozone concentrations did not begin until 1976, when violations in Portland were recorded. Subsequent sampling in 1977 demonstrated that (1) Maine's southwestern coastal areas (south of the characterization area) frequently exceeded the NAAQS, (2) local sources of ozone were at least partly responsible for the violations, and (3) standard violations existed quite far inland and north of the Portland area (Maine Department of Environmental Protection 1979).

Ozone is principally a public health concern. A growing concern exists that ozone may be responsible for "tip burn" disease in eastern white pine. This condition, which can lead to tree death, occurs at relatively low ozone concentrations (i.e., lower than NAAQS requirements; personal communication from R. Campana, Department of Plant and Soil Sciences, University of Maine, Orono, ME; January, 1980).

By studying data on Maine in close detail and in conjunction with data from nearby States and by analyzing wind and other meteorologic factors, it was determined that southern Maine is affected by transport of ozone from other areas, most noticeably the metropolitan Boston area "urban plume" (Maine Department of Environmental Protection 1979).

In 1978, sampling stations for ozone were set up throughout Maine at five sites in five areas. Data gathered at three stations within the characterization area indicated numerous exceedances of the new ozone standard (0.12 ppm) in regions 1 to 4 but none in region 5. However, since more data must be collected to ensure that regions 5 and 6 have reached attainment levels, the State has requested that these regions be declassified.

In order to reduce ozone concentrations to compliance levels, it is necessary to control the emission of volatile organic compounds (VOCs), the major precursor of ozone. The major sources of VOC and amounts released per year in Maine are listed in table 3-7. Information on methods of reducing VOCs have been prepared by the Maine DEP (1979) for the Portland area (region 1).

Effects of atmospheric deposition on coastal ecosystems. Elevated levels of air pollution can reduce the quality of life in the coastal zone. The systems most affected by all forms of air pollution are terrestrial (especially developed areas), lacustrine, riverine, and palustrine. The lacustrine system is particularly sensitive to acid rain. The marine and estuarine systems may be affected directly by heavy metals that enter them via precipitation. Because of the high buffering capacity of salt water, the marine and estuarine systems are not generally affected by the low pH of acid rain.

Table 3-7. Sources and Amounts (tons/year) of Volatile Organic Compounds Causing Air Pollution in Maine.[a]

Source	Tons/Year
Storage, transportation, and marketing of petroleum products	10,600
Industrial processes	905
Industrial surface coating	2516
Nonindustrial surface coating	1512
Other solvent use	2426
Miscellaneous sources (open burning, solid waste disposal, and fuel combustion)	10,534
Mobile sources (e.g., highway vehicles)	56,963
TOTAL	85,516

[a] Maine Department of Environmental Protection 1979.

Acid rain is the dominant destructive constituent of the human-induced atmospheric pollution that affects natural systems in coastal Maine. Acid rain influences natural systems in four ways: (1) by introducing toxic levels of acidity into the environment, (2) by introducing heavy metals and PCB into the environment (particularly near metal smelters and industrial areas), (3) by introducing plant nutrients into the environment, (4) by introducing organic molecules into the environment.

The response of natural systems to acid rain is poorly understood at present but is under investigation. The focus of investigative effort concerning the effects of acid rain on natural systems has centered on the impact of acidity and the effect of heavy metals on natural systems. The impact of acid rain on natural systems in coastal Maine is discussed below.

Acid precipitation. Over the past 30 years, scientists have noted an increase in the acidity of rain in Europe and the United States (Likens et al. 1979 and 1972). In the United States, the most noticeable increases have been measured in the Northeast. This trend is due to the rise in emissions of sulfur and nitrogen oxides accompanying the rise in burning of fossil fuels. The increase in acidity has already brought about changes in the ecology of some Maine lakes (changes have not been studied in coastal lakes) and threatens other natural systems. Acid precipitation tends to interfere with critical ecosystem interactions. Changes in acidity accelerate or retard the chemical release and transport of minerals, nutrients, and heavy metals through biota, soils, and water courses.

A common measure of acidity is pH, which is the negative logarithm of the concentration of hydrogen ions. The pH scale ranges from 0 to 14, with 7 being the neutral point. Values lower than 7 are acidic. Since the pH scale is logarithmic, a change in pH from 6 to 5 represents a ten-fold increase in acidity.

Nitrogen and sulfur oxides enter the atmosphere from various sources. These oxides are converted to strong acids in the atmosphere and transported to the ground by rain and snow. Prior to the burning of massive amounts of fossil fuels, the pH of precipitation in the United States was consistently above 5.0. The first recorded measurement of the pH of precipitation in the United States was made in Maine in 1939; it was 5.9 (Likens et al. 1979).

Over the last few decades, the pH of precipitation over the Eastern United States has slowly decreased to a point between 4 and 4.5. This represents at least a ten-fold increase in acidity, an increase that is correlated with increased concentrations of sulfate and nitrate oxides emitted into the atmosphere over the past 20 years (Likens et al. 1979). Changes in acidity already have caused environmental degradation, particularly in sensitive freshwater systems (Davis et al. 1979; Johnson 1979; Hendrey et al. 1976; Schofield 1976; and Gorham 1975). Since oxides may remain in the atmosphere for a long period of time, local pollution may be transported many miles before it is washed from the atmosphere by rain.

The vulnerability of natural ecosystems to atmospheric pollutants, predominantly acid rains, is influenced by climatic, geographical, topographical, morphometrical, biotic, and human inputs (Gorham and McFee 1978). Chief among the climatic factors are the amount and type of precipitation, wind speed and direction, and seasonality. Rain and to a lesser extent snow introduce acids and metals into the ground. Since Maine receives about 40 inches (102 cm) of precipitation per year, ample opportunity exists for atmospheric deposition. Although rain introduces acids relatively quickly, snow cover tends to store acids, so that spring thaws can become sudden pulsations of pollution into aquatic systems (Gorham and McFee 1978; and Hornbeck et al. 1975).

Seasons and prevailing winds determine types of precipitation. Acidity of precipitation at Hubbard Brook, New Hampshire, was found to be maximal in the summer months, intermediate in the spring and fall and minimal in winter (Hornbeck et al. 1975). The high summer levels are caused by the prevailing winds that transport atmospheric pollution from the industrialized northeastern and central States into northern New England. In cooler months, northwestern prevailing winds bring air from less industrialized regions, probably reducing the relative influence of acidity.

In many cases, geological factors influence the buffering capacity of natural systems. Areas with granite and metamorphic silicaceous bedrock and thin soils are most sensitive to acid rains because of their poor buffering capacities. Soil texture, thickness, and structure can greatly influence the effects of acids and heavy metals. The soils in coastal Maine are generally thin and of granitic and metamorphic origin.

Biotic factors are important in altering acidity and in the uptake of heavy metals and nutrients received from atmospheric deposition. Canopy of hardwood forests can lower the acidity of rain effectively (Eaton et al. 1973). However, the acidity of rain actually may increase as it passes through spruce-fir forests.

Lacustrine, palustrine, and riverine systems are particularly sensitive to acid deposition, due to their relatively poor buffering capacities and/or low flushing rates. Many freshwater systems are underlain by types of bedrock that resist weathering, so that the surface waters have few dissolved ions and consequently are poor buffering solutions. Acids that fall into freshwater systems become partially neutralized. Areas underlain with limestone, on the other hand, neutralize the acid rain quickly. There are very few limestone deposits at present in coastal Maine.

Although detailed studies have not been made of the effects of acid rain on the structure, function, and diversity of freshwater systems, the general effects are known. The lacustrine system has been studied in more detail than the other systems, since the lower turnover rates and poor buffering capacities of lacustrine systems render the effects of acidification on them more obvious (Arnold et al. 1979). In general, lowland lakes, of which the coastal zone has many, exhibit a higher acid-buffering capacity than high altitude lakes. A study of 37 lowland lakes in 1978 (Davis et al. 1979) indicated that all still maintained acid-buffering capacities. However, 32 of the lakes showed decreases in pH.

One of the more measurable effects of acid rain has been the virtual elimination of fish in acidified lakes, a particularly acute problem in the Adirondacks of New York and the White Mountains of New Hampshire (LaBastille 1979). This effect has not been observed on the Maine coast. Several effects of increased acidity contribute to the decrease in fish populations, including the alteration of calcium levels, which affect reproduction in fish, the alteration of gill functioning, and changes in sodium and chloride levels in fish blood (Mitchell 1979; and Arnold et al. 1979). Survival of fish eggs and larvae is much reduced in acidified waters.

Fish are not the only species affected by high acidity levels caused by acid rain. Deleterious impacts of increased pH in water have been observed in salamanders (Mitchell 1979), bacteria (Likens et al. 1979), zooplankton, phytoplankton, neuston, and in the food web as a whole (Gorham 1978).

In riverine systems in New Hampshire relatively small drainage systems are more affected by acid rains than larger streams (Johnson 1979). This indicates an added buffering capacity by forest vegetation and soils in the larger systems, which reduces the hydrogen ion concentration (Hornbeck et al. 1975). The biological effects of acid precipitation in low water streams have received little attention. Bender (1978) found that pH affects the species composition of periphyton algae.

The impact of acid precipitation deposition on palustrine and estuarine wetlands is poorly understood. Since estuarine wetlands are buffered by the bicarbonate system, most of the acid entering them in precipitation is neutralized.

Palustrine wetlands systems have not been studied but, like the lacustrine systems, they generally are not buffered highly. Many of the impacts on the palustrine systems can be assumed to be similar to lacustrine systems. However, further study of palustrine systems is needed. Many peat lands already possess low pH (well below 5.6) and have little capacity to neutralize strong acids and thus may be sensitive to acid rains.

Terrestrial vegetation is susceptible to acid precipitation. The potential effects of acid precipitation on vegetation include (Tamm and Cowling 1975):

1. damage to protective surface structures, such as the cuticle ,
2. interference with normal functioning of guard cells,
3. poisoning of plant cells through diffusion of acidic substances through the stomata or cuticle,
4. disturbance of normal metabolism or growth processes without necrosis of plant cells,
5. interference with reproductive processes,
6. alteration of leaf-acid and root-exudation processes,
7. synergystic interaction with other environmental stress factors.

Likens and Bormann (1974) have suggested that the reduction in forest growth in northern New England may be correlated with the concurrent acidification of precipitation. Agricultural crops are impacted also and production may be decreased by about 5% (personal communication from S. Norton, University of Maine, Orono, ME; July, 1979). Numerous reports of sickness and death to wildlife have been attributed to air pollution (Newman 1979). Soils are greatly affected by acid rains (Malmer 1976; Tamm 1976; Norton 1976; and McFee 1978). Slow acidification of soils in general decreases plant production (McFee 1978). The effects of acid precipitation in terrestrial habitats include:

1. lowered soil pH,
2. accelerated leaching of plant nutrients and other ions,
3. changes in soil biota,
4. reduction in organic matter decay rates and associated release of plant nutrients,
5. reduction in nitrification,
6. increased aluminum mobility and associated toxicity,
7. reduced availability of phosporus to plants,
8. increased mobility of some organic soil components.

Effects on the soil affect hydrology. For instance, acid precipitation increases aluminum mobility and the aluminum transferred to the lacustrine system has been shown to be toxic to lake fishes (Cronan and Schofield 1979). In coastal areas, sea spray contributes significantly to the chemistry of precipitation (Likens et al. 1979). Consequently, precipitation in coastal areas affected by sea spray may be characterized as dilute sea water, since the atmosphere there contains many of the ions abundant in sea water, the ions Na+ and Mg+, the anion Cl-, and to a lesser extent the cations Ca++, K+, and the anion SO_4 (Likens et al. 1979). These ions tend to neutralize atmospheric acids. Boyce and Butcher (1976), in studying the effect of a local source on the composition of precipitation in south-central Maine, found a sharp gradient of decreasing sodium concentration with increasing distance from the ocean. Inland, high concentrations of sodium were associated with constant east and northeasterly winds, which carry marine air into the region. The pH levels in rain during periods in which these winds prevailed was 5.8, compared with levels of 4.0 and 5.0 when the precipitation was not influenced by marine air.

These limited data suggest that much of the effect of acid precipitation in coastal areas is neutralized by marine and estuarine sea water and by marine aerosols generated in the coastal atmosphere by sea spray and onshore winds.

Oil Pollution. Maine is dependent on imported petroleum. Presently, no refineries exist in Maine, although during the past decade numerous proposals have been made to site a major refinery in coastal Maine because of its deep-water port facilities [e.g., Sanford (Portland), Machiasport, Eastport, and Searsport]. The Maine coast can be affected at present by any major spill occurring on Georges Bank as a result of oil and gas development there. At present, Portland Harbor (region 1) handles more commercial shipping (in tonnage) than any other New England port whose major cargo is crude petroleum and petroleum products. Tank farms with a capacity of 3.7 x 10 barrels (1.55 x 10 gal; 5.87 x 10 l) border the harbor,and their pipelines carry oil to Canada. A proposal is active that would expand these facilities. Other coastal areas with traffic in petroleum include Harpswell (region 1), Upper Penobscot Bay (region 4), and Machias Bay (region 6).

Shenton (1973) and Hyland (1977) reviewed the incidence of oil spills along the Maine coast from 1953 to 1976. Since 1976, the Maine DEP has documented the occurrence of reported oil spills. Detailed statistical reports on the occurrence, location, and magnitude of reported oil spills in Maine for each year are available from the Maine DEP.

From 1976 to 1978, the Maine DEP reported 950 spills of 175,465 gal (665,012 l) of petroleum products in Maine, most of which were in the Portland (region 1) and Penobscot Bay (region 4) areas. Records of oil spills before this time are not directly comparable. Oily wastes from developed areas are another source of oil pollution entering aquatic systems through runoff into storm sewers in many coastal towns and cities.

Three notable oil spills have occurred in coastal Maine (Hyland 1977): (1) the *Northern Gulf* spill in Muscongus Bay (region 3) in 1963 [5510 tons (5000 t) of crude oil], (2)leakage in 1971 from a fuel storage facility at Long Cove in Penobscot Bay [region 4; a minimum of 15 tons (14 t) of No. 2 fuel oil and jet fuel]; and (3) the 1972 *Tamano* spill in Casco Bay [358 tons (325 t) of No. 6 fuel oil].

None of these spills has been assessed thoroughly from an ecological standpoint. In the first two incidents, only effects on commercially important shellfish were investigated. The *Northern Gulf* spill caused an estimated loss of 66 to 230 tons (60 to 209 t) of soft clams and 17 tons (15.2 t) of impounded lobsters (Hyland 1977). Mayo and coworkers (1974) reported crude oil concentrations of over 4000 ppm in Muscongus Bay 11 years after the spill.

In 1973, clam transplantation studies were conducted at Muscongus Bay to evaluate any continuing impact of the weathered oil (Dow 1975). Survival was only 12.8%, compared to 78.1% survival in a control area. A decline of 65% in the annual growth rate was noted.

The Long Cove spill was especially toxic. Within 2 weeks of the 6 March 1971 incident, an estimated 4.5 million commercial-sized clams died (Dow 1975). Of the 165 tons (150t) believed to exist in the area at the time of the spill, 13% died by 30 March, 25% by 31 July, 55% by August, 1972, and 86% by August, 1974 (Dow and Hurst 1975). Additionally, surviving clams showed a high incidence of gonadal tumors (malignant neoplasms; Barry and Yevich 1975). Up to 26.6% of the individuals in some samples were afflicted. No tumors were found in clams from control areas. Highest incidences correlated with areas receiving the highest amounts of oil. Subsequent histopathological examinations of clams from other parts of the State, including the chronically polluted inner Portland Harbor, have revealed that tumors in clams are rare, which may suggest that the jet fuel or some component of it is the causal agent (personal communication from J. Hurst, Maine Department of Marine Resources, West Boothbay Harbor, ME; January, 1980).

Further studies of Long Cove have confirmed and expanded the above results. Gilfillan and coworkers (1977) concluded that 5 years after the spill "major biological effects were still readily apparent" in the clam population. These effects include absence of recruitment, continuing incidence of gonadal tumors, and a significantly reduced growth rate. Growth rate reduction could be related to the concentration of aromatic hydrocarbons in tissues. Sediment analyses conducted in the summer of 1976 showed that many stations within the cove still contained over 125 ppm weathered hydrocarbon material that was similar to the spilled petroleum. These authors also report that for some time after the spill marine bait worms (e.g., bloodworms) from the area showed high mortality during shipping, and dealers ceased buying them.

It has been reported recently (Dow 1978) that clams have successfully established themselves in Long Cove, in fairly clean sediments that have been redistributed over areas of oiled sediments by winter storms. These clams continue to survive and grow until they reach the size at which their burrow intersects the oiled sediment horizon, at which time they die.

The impact of the 1973 Tamano spill on several components of the marine system was investigated in July, September, and November of 1972 and again in August, 1973 (The Research Corporation of New England 1975). All groups of biota were affected adversely; amphipods were completely absent from severely oiled sites. The intertidal mudflats were most severely affected, followed by intertidal rocky shores and subtidal benthic communities. Density and diversity declined, and accumulations of petroleum hydrocarbons were found in tissues. Waterbirds experienced high mortalities. By November and to a greater extent by the next August, some recovery among waterbirds was noted. However, severely oiled rocky areas were still void of biota in 1973, and recruitment of shellfish to the oiled flats has not been observed.

The most important factor controlling the extent of damage to an intertidal area from spilled oil is its exposure to wave-action (Owens 1978). On shores of high-wave energy, the oil is dispersed quickly by the violent action of the waves, whereas on shores of low-wave energy the oil may persist for years (Keizer et al. 1978). The removal of most of the oil by natural agents after a moderate oiling of an exposed rocky shore may take only 3 to 4 months (Smith 1968).

Approximately 1 year after the Nova Scotia coast was oiled severely, only small amounts of oil remained on the rocky shores (Thomas 1973). Since much of this oil was deposited in upper intertidal areas, where the least amount of wave action is present, oil remained there for longer periods and delayed recolonization of some biota. Oil deposited during spring tides is particularly persistent. Small amounts of oil may persist for some time in areas such as rock crevices, seaweed, barnacle, or mussel beds (Nelson-Smith 1973).

In combination with wave-action, the physical nature of a shore determines the rate at which oil is dispersed. Rocky shores are cleansed naturally more easily than sand beaches, and the cobble or gravel beaches are less easily cleansed than the sand beaches. Sand and mud flats and salt marshes are the least easily cleansed habitats (Owens 1978).

The formation of sea ice or an ice foot, which may cover up to two-thirds of the intertidal zone, is characteristic of estuaries and embayments of coastal Maine. These formations sometimes trap oil between the sediment and the ice, where the toxic element will remain until the ice breaks up. Through wave-action oil also may become trapped between layers of ice or between layers of sand, creating a source of dispersal over several months. These formations of ice can serve as a protective covering to the underlying sediments until the spilled oil is dispersed (Owens 1978).

Many species of bacteria, fungi, and yeasts are capable of degrading petroleum hydrocarbons. Each species is limited in the types of hydrocarbon it may attack. Although the rate of microbial degradation is related directly to temperature (Nelson-Smith 1973), most investigators believe that the microbes are limited most by dissolved oxygen, phosphates, and nitrates (Colwell et al. 1978). The activities of deposit-feeding benthic invertebrates have been found to significantly increase the microbial degradation of petroleum hydrocarbons in oiled sediments (Gordon et al. 1978). The very slow microbial degradation of petroleum hydrocarbons on, in, or under a layer of ice may have a considerable impact on the estuaries of Maine, which sometimes are covered with ice during the greater portion of winter.

The effects of oil on the food chain in a habitat vary. The extent of damage is a function of many factors, including the toxicity of the oil, the duration of exposure, environmental conditions (including temperature), time of year, the physiological state of the organisms, and the degree to which the organisms are subjected to other forms of stress.

Toxic effects of oil on small benthic organisms include coating and asphyxiation, ingestion, and the destruction of juveniles. Among the sublethal effects are abnormal growths in soft-shelled clams, abnormal development of barnacle and sea urchin larvae, delayed moulting of lobsters, abnormal sexual behavior of fiddler crabs, interference with chemoreception in lobsters, amphipods, and mud snails; interference with reproduction in birds, and altered behavior in waterbirds (Snyder et al. 1973; and Butler et al. 1974).

Communities of organisms have been impacted by oil spills. At Chedabucto Bay, Nova Scotia, Thomas (1978) found lower animal diversity at sites that were oiled 6 years before the sampling than at control sites that were oil-free. At West Falmouth, Massachusetts, the spillage of No. 2 fuel oil completely decimated the benthic fauna at severely oiled sites (Sanders 1978).

The most damaging effects on the marine system are caused by the chronic low level inputs of petroleum hydrocarbons. These remain in the sediments and may be metabolized by or accumulated within the tissue of benthic species and passed through the food chain to the commercially important species.

Fish, marine mammals, and birds are affected by spills through external oiling (especially birds) and the ingestion of oil (through the food chain and during preening). In addition, oiling significantly reduces the hatchability of bird eggs (see Chapters 11, 13, and 14, "Fishes," "Marine Mammals," and "Waterbirds" respectively).

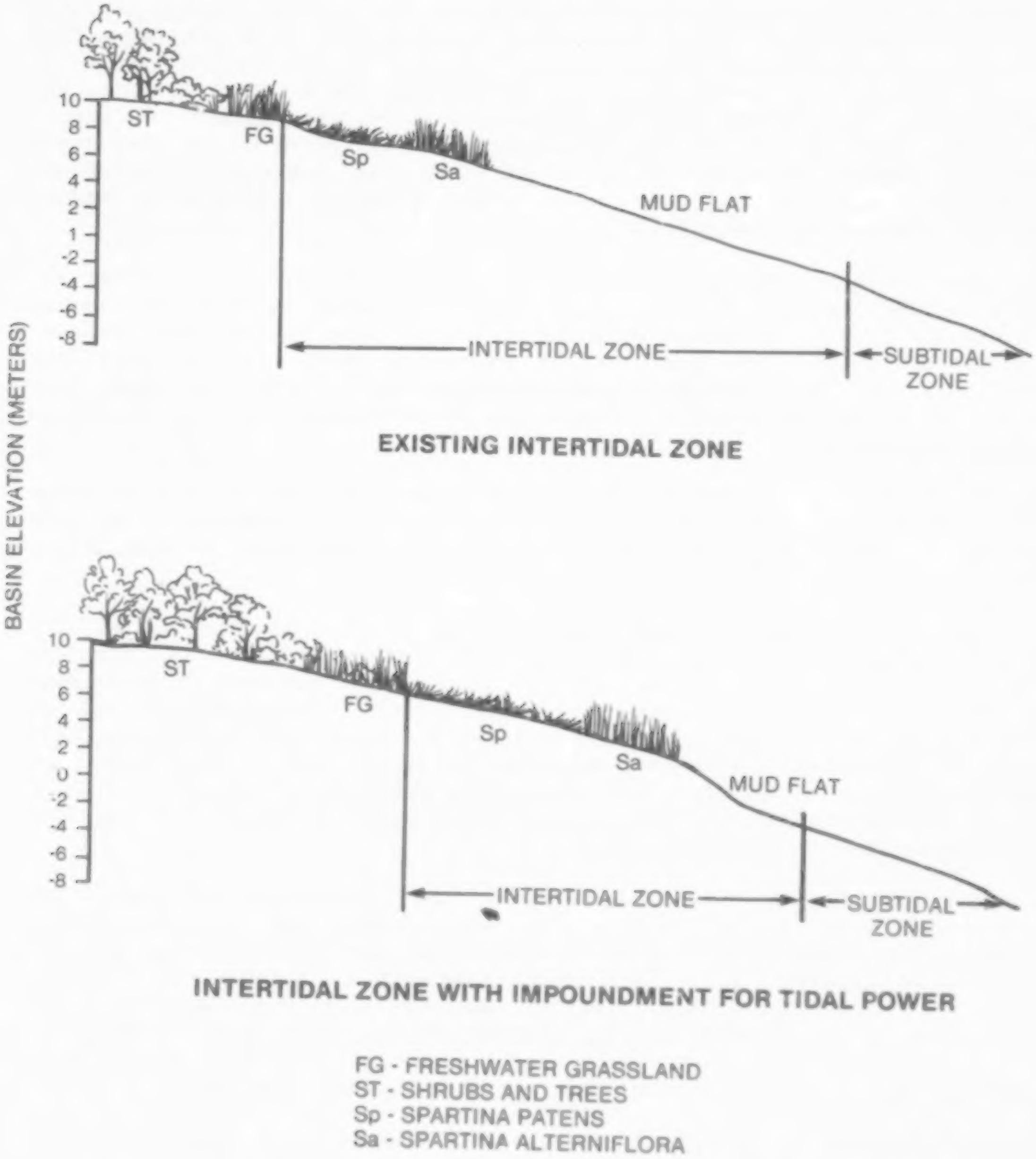
Dams

A significant potential exists for low-head hydropower development in coastal Maine. The U.S. Army Corps of Engineers (1979), in a recent inventory of potential hydropower sites, identified 276 dam sites in coastal Maine (see atlas for locations), which constitutes 20% of all the dams in the State. Most of these are on rivers or the outlets of lakes. The possibility also exists for generating power at dams constructed in tidal waters along the eastern coast. The impacts of impoundments are discussed below.

Effects of dams on marine and estuarine systems. Dams and impoundments can have major effects on marine and estuarine systems (Copeland and Dickens 1974). These structures typically alter the volume and rate of freshwater flow into estuaries. Alterations, in turn, can change the physical qualities of the receiving waters, especially circulation, salinity, sedimentation, temperature, shoreline erosion, flushing, ice-formation, and nutrient levels. Impoundments also can act as settling basins, reducing sediment load and, thus, reducing nutrient and sediment supply to intertidal areas and beaches. Such changes in hydrography, geology, and chemistry can alter estuarine biota significantly. The characteristics and magnitude of these changes depend on the nature and duration of the induced alterations and on specific physical and biological characteristics of estuaries receiving the modified inflow.

Tidal power projects are of two general types: dams utilizing both incoming and outgoing tidal currents, and impoundments using incoming tides to store water until power is needed later. Both types can alter tidal dynamics, water temperature, wave action, surface and bottom currents, sedimentation, and erosion patterns. These changes subsequently can influence aquatic biota. For example, if the Fundy Tidal Power Project (Bay of Fundy, Canada) is built the mean high water level in the bay would decrease 1.3 to 2.9 feet (0.4 to 0.9 m). The low water level would rise so as rarely to fall below existing mean low water, causing mean sea level to rise approximately 9 feet (2.8 m; figure 3-2; Hodd 1977). These changes would cause a vertical compression of the intertidal zone, halving the tidal excursion and thus changing intertidal zonation. In turn, the latter change would bring about a partial displacement of intertidal macroalgae, salt marsh and epibenthic algae, and associated fauna. Much of the intertidal habitat would be altered and its productivity would be impaired greatly. About half of the intertidal plant communities would cease to be productive.

Numerous ecological changes also could take place in the impounded tidal water, resulting in biological alterations. Decreased wave exposure along impoundment fringes would favor Ascophyllum over Fucus (seaweeds) in rocky


BASIN ELEVATION (METERS)
10
8
6
4
2
1
-2
-4
-6
-8
ST
FG
Sp
Sa
MUD FLAT
INTERTIDAL ZONE
SUBTIDAL ZONE
10
8
6
4
2
0
-2
-4
-6
-8
ST
FG
Sp
Sa
MUD FLAT
INTERTIDAL ZONE
SUBTIDAL ZONE
FG - FRESHWATER GRASSLAND
ST - SHRUBS AND TREES
Sp - SPARTINA PATENS
Sa - SPARTINA ALTERNIFLORA

EXISTING INTERTIDAL ZONE

INTERTIDAL ZONE WITH IMPOUNDMENT FOR TIDAL POWER

Figure 3-2. Conceptual effect of a new tidal regime on a generalized intertidal zone (Hodd 1977).

areas and promote salt marsh development on finer substrates. Warmer water temperatures would stimulate growth of some benthic plants and possibly accelerate grazing by littorina snails and urchins in intertidal and subtidal areas respectively. Increased sedimentation in impoundments would decrease the rocky substrata available for macroalgae and increase the soft, elevated substrata suitable for marsh grasses. Organisms would be displaced from previously occupied heights to new levels. Benthic invertebrates would be severely affected as portions of many populations would not survive the new tidal regimes. As habitats were recolonized, more gradual changes in benthic populations might result through sedimentation. Organisms up the food chain potentially would be affected by changes in the benthic invertebrate populations. Shorebirds, in particular, might be impacted greatly in feeding areas (see chapter 14, "Waterbirds").

Tidal power projects also could affect fish and wildlife populations directly. Changes in riverine and estuarine conditions could result in decreased homing of anadromous fishes. Fishways might be needed to allow for upstream passage. Depending on the level of operation and equipment used, turbine mortality might be a serious problem to fish and other aquatic life. Ice might form more readily in an impoundment, resulting in decreased use by wintering waterfowl populations.

Reduced tidal flushing behind a tidal dam could degrade water quality if large amounts of untreated sewage or other pollutants accumulated in the impoundment. This would be of special concern in relation to aquaculture sites.

Effects of dams on freshwater habitats. Impoundments behind the hydropower dams can affect the physical, chemical, and biological characteristics of rivers severely. In Maine, where hundreds of small dams have been built on rivers and their tributaries, impoundments are of particular concern. Dams and their associated storage reservoirs frequently alter flow and temperature regimes above and below the dam. They also may create barriers to upstream and downstream movements of migratory fishes. Dams and barriers on Maine streams are the major cause of the historic decline of anadromous fish resources in Maine.

The magnitude of the impacts of an impoundment depend upon the size of the dam, operating mode (run-of-river or store-and-release), the flow rate through the impounded area, turbine size and speed, and the retention time of water within the impoundment. Generally, larger dams with relatively low average flow rates, wide ranges in operating flows, and long retention times, will have the most severe impacts on the stream and its biological community. Since most Maine dams are relatively small, their impacts, while significant, are probably not as severe as the impacts of larger dams might be.

Regardless of its size, any dam can be expected to have some impacts. After a dam is built the area immediately upstream typically is inundated, converting it from a running-water habitat to a standing-water habitat, with concurrent changes in its biological community. Bottom fauna in a newly impounded area are usually very unstable and frequently are dominated by chironomid midge larvae (Hynes 1970). Gradually, biological communities stabilize, sometimes resembling communities typical of lakes in the same area. In other instances, floral and faunal assemblages never may be as stable as lacustrine areas, because of large water-level fluctuations (drawdowns) caused by dam operations, especially power generation. Shoreline habitat is particularly endangered by water-level changes.

Reduction of peak flows downstream of a dam can reduce scouring and cause organic detritus to accumulate (Ridley and Steel 1975). This in turn can favor rooted aquatic vegetation and disrupt invertebrate and fish populations. Reduction of peak flows also can interfere with environmental cues that trigger fish migrations.

Impounded water usually warms slower in spring and remains warm longer in fall than freely flowing water, resulting in a more even temperature regime downstream (Ridley and Steel 1975). Hence, releases from impoundments can change temperatures downstream and interfere with the normal timing of the life cycle of some stream animals (e.g., smallmouth bass, Atlantic salmon, and brook trout). Similar changes also can occur in the impoundment itself and in upstream areas.

Surface water released from an impoundment often contains more algae and less silt than freely flowing water (Ridley and Steel 1975). This can change biomass and sediment transport and buildup downstream, affecting vegetation, macroinvertebrates, and fish. Increased transport of planktonic algae is particularly important, because it can favor populations of filter feeders, such as larval blackflies, which can then produce a significant nuisance effect as adults emerge.

The most obvious and frequent impact of a dam is its interference with the migration of fish. Studies in Maine and Canada show that at least 5% to 10% of adult Atlantic salmon are unable to migrate past a dam, even where fishways exist (DeRoche 1967). Of course, dams without operating fishways impede far more fish.

Some fish are more likely to be impeded by dams than others. For instance, salmon, which can clear obstacles 11 feet (3.4 m) high under favorable conditions (Jones 1959) are much more likely to pass barriers than Atlantic or shortnose sturgeon, which are sluggish swimmers, or American shad or striped bass, which are not prone to leaping. In Maine, the only major anadromous fishes that pass barriers and fishways easily are alewives and salmon. The American eel, a catadromous fish, also passes barriers well (see chapter 11, "Fishes").

Dams also can block downstream migrations of young fish. Most downstream migrants swim along the bottom, so that many young fish fail to take advantage of dam spillage and fishways. In the Androscoggin River, a 10% loss of river-produced Atlantic salmon smolts would occur at each power dam encountered during downstream migration and a 5% loss of tributary-produced smolts for each dam encountered (DeRoche 1967). Higher mortalities, about 11% per dam, could be experienced during unusually poor water years, when dam spillage is nearly nil and water is passing mostly through turbines (Schoeneman et al. 1961).

Dams and stream pollution have been implicated as the major causes of the reduction of anadromous fish runs in Maine to far below historical levels. Striped bass virtually have been eliminated as a spawning population.

Spawning populations of the American shad and sturgeon species also have been greatly reduced. Atlantic salmon, whose runs were greatly reduced, are now beginning to respond to intensive restoration efforts. Anadromous alewives and rainbow smelt, although generally abundant, have experienced many local disruptions. Migrations of nonanadromous resident fishes, such as trout and landlocked salmon, probably also have been disrupted, although this situation has received relatively little attention.

Dams are present at the outlets of many lakes in the coastal zone (a partial list is given in table 3 in the appendix to chapter 7,"The Lacustrine System"). With few exceptions, these dams have been built on natural lakes and have raised the maximum water levels. These dams serve, or once served, purposes including ice production, powering of mills at outlets, controlled release of water for recreation, and electrical power production. Water-level manipulation at dam sites may affect lacustrine biota and fish spawning areas. Potential adverse effects of hydroelectric dams exist at Branch Lake (region 5) and Toddy Pond (region 4). Numerous dams at lake outlets have fallen into disrepair because the original purposes of the dams no longer exist and laws are inadequate to enforce maintenance. These and the still-functional dams are matters of State and local controversy. Conflicts in relation to desired water levels exist between dam operators, boatsmen, fishermen, and shoreline cottage owners.

Construction

Construction includes building activities associated with homes, walls, piers, jetties, dams, industries, roads, parking lots, bridges, and walkways. These developments exist in all regions of coastal Maine in varying extent and generally relate to population density (see "The Socioeconomy" in chapter 2). The impacts associated with construction are reviewed below. Impacts of the various types of developments are covered by facility (e.g., piers and wharves are discussed under "Ports and Navigation" above).

In all aquatic systems, the adverse effects of construction projects include loss of habitat, altered stream flow, increased turbidity, and increased sedimentation, which forms a layer of silt and resuspensed pollutants from benthic sediments. The impacts of construction vary with the type of development, degree of landscape and drainage pattern alterations, density of individual development projects, proximity of the operation to the water, and the basic ecological sensitivity of the area (Clark 1974). The short-term impacts of construction projects on the food web are similar to those of dredging. Construction often promotes erosion, blocks sediment flow, and redirects wave energy.

The inevitable devegetation caused by construction in nearshore and adjacent upland areas increases erosion. Erosion of cleared land usually results in the introduction of a high load of sediment into watercourses. Palustrine and lacustrine systems in coastal Maine are especially vulnerable to high sediment loads, as water flow in these systems usually is restricted.

Soil erosion is a serious but controllable problem. Unvegetated soil is unstable and erodes into adjacent waters, causing siltation and sedimentation. Soil particles in suspension cause turbidity in water, preventing light penetration and thereby hindering photosynthesis and plant production.

Siltation also clogs the gills of fish and the breathing apparatuses of invertebrate organisms, which serve as food for fish and birds. Eroded soil that has settled on the bottom of an aquatic system can smother food items of bottom-feeding fish and may render the bottom unsuitable for certain bottom-spawning fish.

Instream and nearstream construction activities may have substantial impacts on riverine systems. Instream construction may involve the placement of dikes of rock, timber, or other material within a stream with the objective of modifying streamflow. Or it may involve construction of shoreline or midstream structures, such as boat launching ramps, piers, or bridge abuttments, which modify the stream environment. Nearstream construction refers to any construction activity (e.g., home-building and road construction) that occurs near enough to a stream to have discernable effects on it.

Instream construction almost inevitably results in disturbance of stream sediments. Most types of near stream construction involve earth-moving and/or vegetation removal, which increases the soil's susceptibility to erosion. Frequently, much of the eroded material from construction sites on or near streambanks is washed into the stream. The increased movement of stream silt or eroded soil particles increases the turbidity (cloudiness) of the stream water. Frequently, plant nutrients, especially phosphorus, that are bound to soil particles are released when the particles are eroded and carried into the stream. This may result in eutrophication of the stream (see "Domestic Sewage" above). Heavy metals, such as chromium (from tanneries) and mercury (transported by air currents), may be found in some Maine soils and sediments, as may certain pesticides and other toxic materials. These potentially harmful materials may be released when soils and stream sediments are disturbed.

In addition to sediment disturbance, instream construction may have direct effects on the stream environment through the structures placed in the stream. These structures frequently deepen channels by obstructing stream flow along the streambanks (Yorke 1978). This may cause localized flooding, as high flows that would otherwise be carried by the channel with no difficulty are held up and spill over onto the floodplain. The placement of structures within a stream often increases the diversity of stream habitats available, thus having a potentially beneficial effect on the number and diversity of stream organisms inhabiting the site. However, if siltation occurs in the low water velocity pockets downstream of the emplaced structures, habitat diversity in these areas will be reduced. Construction activities that remove streambank vegetation alter the light penetration and temperature regimes of the stream. This in turn affects the composition of stream biological communities.

REGULATIONS GOVERNING HUMAN ACTIVITIES IN THE BIOLOGICAL SYSTEMS OF COASTAL MAINE

The regulations governing freshwater, (palustrine, lacustrine, and riverine systems), tidal (marine, estuarine, and riverine systems) and terrestrial habitats are summarized below.

In addition to those pertaining to habitats, numerous regulations exist concerning native species and their habitats (e.g., the Endangered Species Act, Migratory Bird Conservation Act, and Marine Mammal Protection Act). These laws, and their application to coastal Maine, are covered in the discussion of the species or group of species involved (chapters 11 to 20). A list of Federal laws and treaties that affect sport fish and wildlife is included in appendix D. A summary of State laws and administrative agencies pertaining to the regulation of activities in coastal systems is given in table 3-8.

Regulations Pertaining to Palustrine, Lacustrine, and Riverine Systems

In Maine, limited direct Federal and State controls exist over palustrine, lacustrine, and riverine systems. The federal agencies with direct regulatory authority over Maine's freshwater aquatic habitats are the Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (COE). The EPA controls discharge of pollutants in all waters and wetlands of the United States. The EPA can rescind a State program. Any activities involving the discharge of dredged or fill material in United States waters, including all adjacent wetlands, are under the permit authority of the COE.

Although it has no direct regulatory authority, the U.S. Fish and Wildlife Service (FWS) plays an important advisory role in the issuing of permits by the COE and EPA. Under the Fish and Wildlife Coordination Act, the FWS assesses the impacts on fish and wildlife of all water and water-related land resource development projects that are funded by the Federal Government or are constructed under a Federal permit or license. Federal permits for water-related development are reviewed by the FWS to encourage avoidance of adverse impacts on fish and wildlife and their habitat, particularly wetlands. Also, under the Migratory Bird Conservation Program and the Land and Water Conservation Program, the FWS can acquire habitat (significant migratory waterfowl habitat, habitat for endangered species, important wildlife areas, and recreational and wilderness areas) that may include wetlands and other habitats. These acquisitions become part of the National Wildlife Refuge System.

Other Federal agencies that play an indirect role in the regulation of freshwater habitats in coastal Maine are the U.S. Forest Service (research and management in relation to forest practices), Soil Conservation Service (technical assistance programs in relation to resource conservation), National Park Service (acquisition and management), and U.S. Geological Survey (research). In addition, Executive Orders 11988 (Floodplain Management) and 11990 (Protection of Wetlands) require each agency to take steps to minimize impacts on, restore, and preserve floodplain and wetland areas.

On the State level, 11 laws exist to manage coastal resources by guiding development and by conserving natural resources declared by the State municipalities to be in need of protection. Of the 11 laws, eight pertain to freshwater aquatic systems in organized townships and one pertains to these systems in unorganized townships. The laws regulate uses of lakes, rivers, streams, brooks, and wetlands adjacent to these habitats. Great ponds (lakes) as defined by the State include natural lakes >10 acres (4 ha) and artificial lakes >30 acres (12 ha) and owned by two or more parties. This legislation

Table 3-8. State Laws and Administrative Agencies Regulating Use of Coastal Maine Habitats

System and law	Administrative agency[a]
Palustrine, Lacustrine, and Riverine	
Protection and Improvement of Waters	BEP
Site Location of Development Act	BEP and LURC
Solid Waste Management Act	BEP
Oil Discharge and Prevention Control Act	BEP
Stream Alteration Act	MDIFW
Mandatory Shoreland Zoning Act	SPO
Subdivision Law	MPB and LURC
Land Use Regulation Law	LURC
Great Ponds Act	DEP
Estuarine and Marine	
Site Location of Development Act	BEP
Coastal Wetlands Act	BEP and LURC
Mandatory Shoreland Zoning Act	SPO
Protection and Improvement of Waters	BEP
Oil Discharge Prevention and Pollution Control Act	BEP
Marine Resources Management Law	MDMR
Land Use Regulation Law	LURC
Terrestrial	
Mandatory Shoreland Zoning Act	SPO
Subdivision Law	MPB and LURC
Site Location of Development Act	BEP
Solid Waste Management Law	BEP
Land Use Regulation Law	LURC
Protection and Improvement of Air Law	BEP

[a] BEP = Board of Environmental Protection; MDIFW = Maine Department of Inland Fisheries and Wildlife; SPO= State Planning Office; MPD= Municipal Planning Board; LURC= Land Use Regulation Commission; DEP= Department of Environmental Protection; and MDMR= Maine Department of Marine Resources.

does not cover a significant number and acreage of small wetlands that do not drain or connect with lakes or streams.

The Board of Environmental Protection (BEP) administers four of the seven laws. These include: Protection and Improvement of Waters, Site Location of Development Act, Solid Waste Management Act, and the Oil Discharge and Prevention Control Act. Under Protection and Improvement of Waters, the BEP has licensing authority over all discharges of waste waters into Maine waters (this includes all aquatic systems except those that are confined and retained completely upon the property of one party and do not drain into or connect with any other waters of the State). Besides being licensed, any discharge must receive "best practicable treatment" and must not lower the quality of any classified body of water below its classification level or any unclassified body of water below the classification level that the BEP expects to adopt (see appendix B).

The Site Location of Development Act requires the Board to "...control the location of those developments substantially affecting local environment in order to ensure that such development will be located in a manner which will have a minimal adverse impact on the natural environments or their surroundings." This includes projects >20 acres (8 ha) and those covering more than 60,000 sq ft. This act requires persons proposing such development in an organized township to obtain a permit from the BEP. The permit will be either granted or denied depending upon several criteria, two of which are that no adverse effect on the natural environment will occur and that the proposed development will be built on soil types that are suitable to the nature of the undertaking. The Land Use Regulation Commission administers this law in unorganized townships.

Administered by the BEP, the Solid Waste Management Act includes certain criteria developed to protect ground and surface water resources. The major criteria include: (1) all refuse must be placed at least 5 feet (1.5 m) above the level of groundwater, (2) site sloping must be less than 15%, (3) site boundary limits must not be closer than 300 feet (92 m) to a classified body of water, (4) site boundary limits must not be closer than 1000 feet (305 m) to the nearest residence or potable water supply, and (5) surficial material must consist of well-graded granular material containing from 15% to 40% fine sands and must be relatively free of cobbles. This act is designed to protect all freshwater aquatic habitats from runoff from solid waste in organized townships.

The Oil Discharge Prevention and Pollution Control Act is designed (1) to protect the coast of Maine from damage caused by oil spillage, by prohibiting the unlicensed discharge of oil (coastal waters extending 12 miles, 19 km, seaward), and (2) to regulate the manner in which transfers of oil are conducted. Although the BEP holds the major responsibility for decision-making with regard to licenses and conditions and violations of this act, several other State agencies are involved in administering it. The Division of Oil Conveyance Services of the Department of Environmental Protection is in charge of administering licenses, cleaning up oil spills, and research and development. Enforcement is the duty of the State Attorney General. The Department of Marine Resources (MDMR) and U.S. Coast Guard must be consulted for advice before any anchorage regulation is adopted.

The Stream Alteration Act applies to freshwater aquatic areas. This act, administered by Maine Department of Inland Fisheries and Wildlife (MDIFW) protects (through issuance of permits upon approval by the Commissioner) all streams, rivers, or brooks or the adjacent land against any dredge, fill or construction activities. Any palustrine wetland adjacent to or contained within a stream, river, or brook is protected under this act. Certain lakes also are protected, as this law applies to tributaries, of which lakes are often a part. A large number and acreage of palustrine wetlands and some lakes are not regulated under this act.

The Mandatory Shoreland Zoning Act, administered by the State Planning Office, requires all organized towns to establish zoning controls on all navigable ponds, lakes, rivers, and streams and ocean frontage (land 250 feet or 76 m within the high water mark). Palustrine wetlands, steep slopes, and floodplains associated with these water bodies are classified as Resource Protection Districts. Palustrine wetlands not associated with the above types of water bodies may be zoned by individual towns as Resource Protection Districts, but this is not a requirement of the law. Those towns that have failed to comply with Mandatory Shoreland Zoning Act are under State zoning jurisdiction.

The Subdivision Law requires all municipal authorities in organized townships to assure that a proposed development meets certain standards. For approval, the proposed development must have (1) a sufficient supply of water, (2) an adequate method of sewage disposal, (3) must not cause undue air and water pollution, soil erosion, or unsafe highway conditions, and (4) must not interfere with scenery. All requests for subdivision (three or more lots created within a 5-year period) approval must be reviewed by the municipal planning board. The Land Use Regulation Commission enforces the Subdivision Law in unorganized townships.

The Land Use Regulation Law promotes principles of sound land use planning in unorganized areas. The Land Use Regulation Commission has planning and zoning powers and development control over townships, plantations, and coastal islands that are unorganized. The areas under its jurisdiction are divided into protection, management, and development districts. Any activities within "protection subdistricts" must be approved by the commission. Palustrine wetlands may be zoned under four of these protection subdistricts (Unusual Wetland, Fish and Wildlife, Shoreland, and Great Pond). Lacustrine and riverine areas may be zoned under six of these subdistricts (Flood Prone, Fish and Wildlife, Great Pond, Recreation, Shoreland, and Unusual Wetland).

The Great Ponds Act, which applies to lacustrine systems, prohibits construction without a permit of causeways, bridges, marinas, wharves, and other permanent structures, and filling and dredging in or on land adjacent to Great Ponds [natural lakes >10 acres (4ha), and artifical lakes >30 acres (12 ha) owned by two or more parties]. The Great Ponds Act may apply to a limited number of open water palustrine habitats that have been classified by the State as Great Ponds. The DEP is the State agency responsible for administering the Great Ponds Act. Most applications are reviewed by DEP staff with recommendations from other State departments (particularly MDIFW) and, in unorganized townships, the Land Use Regulation Commission.

The Critical Areas Program of the State Planning Office influences the regulation of aquatic habitats. This program registers the locations of unique and critical areas, such as unique bogs, rare plants, colonial waterbird colonies, and unusual plant communities.

MDIFW owns, protects, and manages palustrine and riverine wetland areas in the coastal zone. Wetlands under MDIFW ownership are ensured protection.

MDIFW and the FWS (Moosehorn National Wildlife Refuge) have been involved in marsh protection and management programs (palustrine, riverine, and lacustrine wetlands) intended to improve habitats for waterfowl. In addition, these organizations manage coastal wetlands and islands used by migratory birds (see atlas map 3).

Regulations Pertaining to Estuarine and Marine Systems in Coastal Maine

Several direct Federal and State controls exist over the estuarine and marine systems in Maine. Federal agencies with direct regulatory authority over these systems are the EPA, the U.S. Coast Guard, and the COE.

The EPA controls discharge of pollutants in all waters of the U.S., including the estuarine and marine systems. Along with the U.S. Coast Guard, EPA regulates spills of oil and hazardous substances that may occur in the estuarine and marine systems. EPA and COE (COE has the permit authority to regulate activities involving discharges of dredged or fill material in all waters of the U.S.) provide the framework for reviewing proposed discharges of dredged or fill materials to evaluate their physical effects and potential for chemical contamination.

Although the FWS has no direct regulatory control over the estuarine and marine systems, it plays a direct advisory role in regulatory practices. Under the Fish and Wildlife Coordination Act, FWS must assess the impacts on fish and wildlife of all water and water-related land resource development projects that are funded by the Federal Government or constructed under a permit or license. It provides information to Federal construction or regulatory agencies and to permit applicants. Such involvement includes analyzing and reporting on construction proposals and applications for dredge and fill permits issued by the COE, ocean-dumping permits issued by the EPA, bridge and causeway permits issued by the U.S. Coast Guard, license applications submitted to the Federal Power Commission and Nuclear Regulatory Commission, and any proposed Federal construction affecting living fish and wildlife resources. FWS also plays a direct role in regulatory practices concerning the estuarine and marine systems through its acquisition of significant migratory waterfowl habitat (under the Migratory Bird Conservation Act) and of habitat for endangered species (under the Endangered Species Act), and recreation and wilderness areas (under the Water Conservation Act). All acquisitions become part of the National Wildlife Refuge System.

The National Marine Fisheries Service's primary responsibility is to protect and conserve the estuarine, marine, and anadromous fish resources. Twenty Federal laws mandate NMFS involvement in fish habitat protection. NMFS also has an advisory role similar to that of the FWS in evaluating Federal permits. In addition, NMFS has primary responsibility in the designation and management of marine and estuarine sanctuaries.

Other Federal agencies that play an indirect role in regulations concerning the estuarine and marine systems in coastal Maine are the Soil Conservation Service (technical assistance programs in relation to resource conservation), National Park Service (acquisition and management), and U.S. Geological Survey (research).

On the State level, nine laws manage coastal resources found primarily in tidal water, by guiding development and by conserving natural resources identified by the State or municipality as being in need of protection. (Seven of these: the Site Location of Development Act, the Protection and Improvement of Waters Act, the Mandatory Shoreland Zoning Act, the Oil Discharge and Pollution Control Act, the Land Use Regulation Act, the Critical Areas Program Act, and the jurisdiction of the MDIFW in wildlife management areas have been discussed previously, as they apply to freshwater aquatic systems as well.) The Coastal Wetland Act and Marine Resources Management Law pertain exclusively to tidal waters (estuarine, marine, and riverine).

The Coastal Wetlands Act ensures that dredging, draining, filling, or construction of permanent structures on or over any tidal or subtidal land does not (1) unreasonably interfere with existing navigational or recreational uses, (2) cause unreasonable soil erosion, (3) unreasonably interfere with the natural flow of any waters, (4) unreasonably harm wildlife or freshwater, estuarine, or marine fisheries, or (5) lower the quality of any waters. This law is administered by the BEP or by those municipal governments to which permit authority has been granted by the BEP (e.g., Harrington and Southport).

The Marine Resources Management Law, as administered by MDMR, protects any of the renewable marine resources (including fish, shellfish, marine worms, and marine plants) of the State through enforceable regulations of the time, method, number, weight, length, and location a species is taken. Enforcement is carried out by wardens of MDMR.

Regulations Pertaining to Terrestrial Systems

Federal regulations of land-based development primarily concern discharge of pollutants (e.g., air, water, solid wastes, and hazardous wastes). If the project is funded by the Federal Government or involves federally owned land, an Environmental Assessment and/or an Environmental Impact Statement must be filed in accordance with the National Environmental Policy Act.

On the State level, 6 laws have direct regulatory control over development. (Four laws, the Mandatory Shoreland Zoning Act, the Subdivision Law, the Site Location of Development Act and the Solid Waste Management Law, are described above.) The applications of the Land Use Regulation Law and the Protection and Improvement of Air Law to the terrestrial system are summarized below. Individual towns may further control and guide development through municipal zoning and local ordinances. Under the Land Use Regulation Law, the Land Use Regulation Commission was created. This commission is instructed by the law "to extend principles of sound planning, zoning, and subdivision control for the unorganized...townships of the state..." The Commission thus exerts considerable control over development within its jurisdiction. Through zoning, development is directed to areas that have good soils and areas where building has already taken place; and fragile areas that may be unsuitable for construction are avoided.

The Land Use Regulation Commission's jurisdiction is divided into protection, management, and development districts in accordance with the following standards:

1. Protection districts: areas where development would jeopardize significant natural, recreational, and historical resources, including but not limited to floodplains, precipitous slopes, wildlife habitat, and other areas critical to the ecology of the State.

2. Management districts: areas that are appropriate for commercial forestry or agricultural uses, for which plans for additional development are not formulated presently, and in which additional development is not anticipated.

3. Development districts: areas discernible as having patterns of intensive residential, recreational, commercial, or industrial use, or commercial removal of minerals or other natural resources. Areas that are devoted to or suitable for intensive development.

The Commission may delineate such subcategories of the above classifications as may be deemed necessary and desirable to carry out the intent of the law. All major activities occurring within these major districts are under the authority of the Land Use Regulation Commission.

The Protection and Improvement of Air Law is intended to control all air emissions in order to protect public health, property, and natural resources. This law prohibits open burning and specifies the circumstances under which open burning may be conducted. (Agricultural burning, burning for the disposition of materials generated by the demolition of a building, burning to clear land prior to construction, burning to control or prevent disease, and burning for training, research, and recreational purposes all require permits.) Forest rangers or town forest-fire wardens may grant open burning permits. All permits for burning carry a requirement that the environment, public health, and property not be endangered.

The Clean Air Act (a Federal law) is summarized in appendix C.

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